This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

PL RESEARCH LIBRARIES

433 06908004 6

George H. Marsden,
Clare College,
Cambridge.

Feb. 1914.—

LC

To

Sir Robert Stawell Ball Knt. FRS

In accordance with
the wishes of the late
Prof. Henry Carvill Lewis, M.A., F.G.S.
Mrs Carvill Lewis
has the honour to present
Sir Robert S. Ball
with a copy of
Prof. Carvill Lewis' work on
The Glacial Geology of Great Britain,
and respectfully asks that an
acknowledgement of the due receipt of
the same may be sent to her.

(Address)
Mrs Carvill Lewis,
C/o. Messrs J. S. Morgan & Co.
22, Old Broad Street,
London, E.C.

THE GLACIAL GEOLOGY

OF

GREAT BRITAIN AND IRELAND

PAPERS AND NOTES ON THE

GLACIAL GEOLOGY
OF
GREAT BRITAIN AND IRELAND

1

BY THE LATE

HENRY CARVILL LEWIS, M.A., F.G.S.

PROFESSOR OF MINERALOGY IN THE ACADEMY OF NATURAL SCIENCES, PHILADELPHIA
AND PROFESSOR OF GEOLOGY IN HAVERFORD COLLEGE, U.S.A.

EDITED FROM HIS UNPUBLISHED MSS.
WITH AN INTRODUCTION
By HENRY W. CROSSKEY, LL.D., F.G.S.

LONDON
LONGMANS, GREEN, AND CO.
AND NEW YORK: 15 EAST 16th STREET
1894

All rights reserved

I, I.

THE NEW YORK
PUBLIC LIBRARY
150276A
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R 1924 L

THIS WORK

IN ACCORDANCE WITH THE WISH OF THE LATE

PROFESSOR HENRY CARVILL LEWIS

IS DEDICATED TO HIS FATHER

F. MORTIMER LEWIS, Esq.

OF PHILADELPHIA

IN GRATEFUL ACKNOWLEDGMENT OF THE UNFAILING SYMPATHY

AND INTEREST WITHOUT WHICH

HE COULD NEVER HAVE DEVOTED HIMSELF

TO AN ACTIVE SCIENTIFIC CAREER

CONTENTS

PAGE
Introduction xvii
I. Comparative Studies upon the Glaciation of North America, Great Britain, and Ireland 1
II. The Terminal Moraines of the great Glaciers of England .
III. On some important Extra-Morainic Lakes in Central England, North America, and elsewhere, during the period of Maximum Glaciation, and on the Origin of Extra-Morainic Boulder Clay 42
IV. The supposed Threefold Division of the Drift . . . 70
V. The Direction of Glaciation as ascertained by the Form of the Striæ 73

FIELD NOTE-BOOKS

Notes of Observations made in the Field, with their associated References 79

1. Ireland (*First Visit*, 1885)

PAGE
The glaciation of Ireland, and its bearing on American glaciation 83
Queenstown 84
Glengarriff 84
Killarney 87
Dingle Promontory . . . 89
Dingle 89
Valentia 94
Waterville 95
Derrynane 96
Killarney to Mallow . . . 97
Mallow to Limerick Junction, and Tipperary to Cork . . 98
Cork 100
Mallow to Waterford . . . 102
Waterford 103
Caher 104
Caher to Lismore 104
Cappoquin to Tallow . . . 105
Youghal 106
Youghal to Cork 106
Mallow to Tralee 108
Tralee to Limerick . . . 109

CONTENTS

PAGE
INTRODUCTION xvii
I. COMPARATIVE STUDIES UPON THE GLACIATION OF NORTH AMERICA, GREAT BRITAIN, AND IRELAND 1
II. THE TERMINAL MORAINES OF THE GREAT GLACIERS OF ENGLAND .
III. ON SOME IMPORTANT EXTRA-MORAINIC LAKES IN CENTRAL ENGLAND, NORTH AMERICA, AND ELSEWHERE, DURING THE PERIOD OF MAXIMUM GLACIATION, AND ON THE ORIGIN OF EXTRA-MORAINIC BOULDER CLAY 42
IV. THE SUPPOSED THREEFOLD DIVISION OF THE DRIFT 70
V. THE DIRECTION OF GLACIATION AS ASCERTAINED BY THE FORM OF THE STRIÆ 73

FIELD NOTE-BOOKS

NOTES OF OBSERVATIONS MADE IN THE FIELD, WITH THEIR ASSOCIATED REFERENCES 79

1. IRELAND (*First Visit*, 1885)

PAGE
The glaciation of Ireland, and its bearing on American glaciation 83
Queenstown 84
Glengarriff 84
Killarney 87
Dingle Promontory 89
Dingle 89
Valentia 94
Waterville 95
Derrynane 96
Killarney to Mallow . . . 97
Mallow to Limerick Junction, and Tipperary to Cork . . 98
Cork 100
Mallow to Waterford . . . 102
Waterford 103
Caher 104
Caher to Lismore 104
Cappoquin to Tallow . . . 105
Youghal 106
Youghal to Cork 106
Mallow to Tralee 108
Tralee to Limerick . . . 109

IRELAND (*First Visit*, 1885)—*Continued*

PAGE
Belfast to Portrush 110
Portrush to Giant's Causeway . 110
Buncrana to Malin Head . . 110
Malin Head 112
Carndonagh to Buncrana . . 114
Rathmelton to Millford . . 115
Letterkenny to Pomeroy . . 115
Omagh to Sligo 116
Sligo to Rosse's Point . . 116
Sligo to Galway, viâ Mullingar . 116
Aran Islands 116
Athenry to Limerick . . . 117
Limerick to Pallas Grean . . 118
Limerick to Charleville . . . 118
Kilkee, Tarbert, and Listowel . 119
Caher 120
Knocklong 122
PAGE
Abbeyfeale 122
Knocknagashel 123
Newcastle 124
Differences in intensity of glaciation 125
Adare 125
Patrick's Well 127
Charleville to Ballyagran and Darragh 127
Listowel 129
Listowel to Ardfert . . . 130
Caher to Waterford . . . 132
Waterford 132
Cappoquin to Dungarvan . . 133
Dungarvan to Knockboy . . 133
Cappoquin to Aglish . . . 133

2. IRELAND (*Second Visit*, 1886)

Cork to Macroom 135
Cork to Bandon and Clonakilty 137
Cork to Queenstown . . . 139
Queenstown to Haulbowline Island 139
Cork to Waterford . . . 140
Waterford to Clonmel and Thurles 142
Dublin and vicinity . . . 143
Three Rock and Two Rock Mountains 145
Bray 148
Note on kames 149
Howth 149
Dublin to Arklow and Shillelagh 154
Arklow to Gorey 155
Wexford and vicinity . . . 156
Wexford to Waterford, viâ Ballywilliam and New Ross . . 163
Waterford 164
Carrick-on-Suir to Rathgormuck 164
Waterford to Ballycullane and Taylorstown 164
Striæ in county Wexford . . 165
General movement of ice-sheet 166

3. GLACIATION OF DURHAM AND PART OF NORTHUMBERLAND . . . 167
References 167
Newcastle-on-Tyne . . . 170
Durham 172
Durham to Bishop Auckland and Stockton 172

4. GLACIATION OF YORKSHIRE

References 172
York 188
York to Northallerton . . . 189
Thirsk Junction 190
York to Harrogate . . . 190
Harrogate to Pateley Bridge . 191
York to Leeds, Skipton, Hawes Junction, and Northallerton 192

GLACIATION OF YORKSHIRE—*Continued*

PAGE
New Malton to Whitby . . 196
Whitby to Scarborough . . 196
Stockton to Thirsk . . . 193
Danby Wiske to Durham . . 199
Darlington, Guisborough, Saltburn, Lofthouse, Hartlepool . 200
Hartlepool, Ferry Hill, Bishop Auckland, and Richmond . . 203
Richmond, Kirkby Ravensworth, Dalton, and Downholme . 204
Bridlington 206
Speeton and Flamborough . 209
Holderness 218
Kelsey Hill, Hull . . . 221
Hull to York and York to Oulston 222
PAGE
Allerton to Ripon . . . 224
Ripon 226
Masham 229
Leeds 231
Leeds to Louth 232
Louth to Cleethorpes . . . 235
Skipton, Oxenhope, Ingrow, and Halifax 236
Bradford, Bingley, and Ilkley . 238
Burley, Ripon, and Harrogate . 244
Richmond to Knaresborough . 245
Cleethorpes to Sheffield, Derby, and Shrewsbury . . . 246
York to Manchester . . . 247

5. NORTH LANCASHIRE AND CHESHIRE DISTRICT

References 248
Manchester and vicinity. Hyde, Marple, Rochdale, and Bacup 256
Kersal and Swinton . . . 258
Worsley 259
Manchester to Heaton Park . . 260
Staleybridge northward to West Riding 260
Glossop 267
Mosley 268
Ewood Bridge and Rochdale . . 269
Manchester to Middleton Junction, Castleton, Rochdale, and Todmorden 271
Rawtenstall and Rose Grove . 272
Manchester to Bolton, Chorley, and Blackburn 273
Bolton to Bacup . . . 275
Holcombe Hill and Blackburn . 275
Entwhistle and Whalley . . 277
Molyneux to Burnley . . . 278
Colne 280
Stockport 281
Denton 283
New Mills and Hayfield . . 283
Strines to Chinley . . . 285
Macclesfield district . . . 286
Buxton (Derbyshire) and Taxall 289
Great Crosby 289
Adderley to Whitchurch . . 291

6. SOUTH LANCASHIRE, CHESHIRE, AND MIDLAND DISTRICT

From Shrewsbury to Whitchurch, viâ Wem . . . 293
Ellesmere and Oswestry . . 293
Shrewsbury, Wellington, and Much Wenlock 295
Lilleshall 298
Strethill, Coalbrookdale . . 299
Wolverhampton . . . 300
Bushbury Hill 300
Rowley Regis 301
Stourbridge to Six Ashes . . 302
Alveley 302
Birmingham to Wellington and Stafford 303
Stafford 304
Trentham, Longton, and Stoke . 304

7. Drift of the Severn, the Avon and Rugby

PAGE
References 305
Manchester to Nottingham . 308
Annesley Park 311
PAGE
Derby 314
The Trent to Sileby (Mt. Sorrel) 319
Leicester 322

8. East of England

References 328
Sibsey (Lincolnshire) . . . 333
Nottingham to Lincoln . . 334
Ely 335
Ely to Cromer 336
Cromer 337
Hunstanton (Norfolk) . . 340

9. South of England

Hemel Hempstead . . . 341
Leavensden 341
Devon 344
South Hampshire and Isle of Wight 345

10. Wales

References 346
Chester to Ruabon, Mold, Hope, and Rhyl 348
Welshpool, Newton, and Machynlleth to Barmouth . . 350
Portmadoc, Carnarvon, and Bangor to Llanfairfechan . . 351
Craven Arms to Carnarvon . 353
Caermarthen 354
Submergence in South Wales, pre-glacial 356
Glaciation of Wales . . . 356

11. Isle of Man 357

12. Additional References

Submergence in South Wales prior to glaciation . . . 360
Very slight erosive power of extreme edge of ice . . . 360
Evidence in Scotland of two glacial epochs . . . 361
Shells in drift of Cheshire . . 361
Buried valleys, denoting former elevation 362
No submergence in south of England 363
The supposed pluvial period . 366
Levels of glacial shell beds . . 366
Glacial striæ of Great Britain . 367

13. Memoranda and Brief Essays on various Subjects connected with Glacial Geology

Inter-glacial periods . . . 372
Note on submergence . . . 373
Supposed submergence of Great Britain during the glacial epoch 374
Pre-glacial submergence in Scotland 375
Further remarks on submergence 376
The origin of the flints found in drift 378

MEMORANDA AND BRIEF ESSAYS—*Continued*

Marine shells in the drift . . 378
Eskers 383
The fringe 383
Marginal lakes and the fringe . 384
Falls of ancient rivers . . 386
Scotch till and boulder clay . . 387
Pleiocene of England . . 388
Extra-morainic lakes in America as illustrative of those in England 389
The three Rhines—Europe, Ireland, and America . . . 390

APPENDIX A

INTRODUCTORY NOTE 393

EXTRACTS FROM THE MSS. OF MR. PERCY F. KENDALL, F.G.S. (*Lecturer on Science at the Stockport Technical School*)

I. Existence of land-ice in East Lancashire and Cheshire; infra-drift surfaces 394
(1) The Levenshulme section 394
(2) The Manchester and Liverpool Ship Canal sections . . . 397
II. The glacial phenomena of the Lancashire and Cheshire area, considered with reference to the supposed threefold division of the drift 410
III. Local drifts and their junction with the general glacial drift . 413
IV. The characteristic erratic blocks of West Lancashire and Cheshire 417
V. The Pennine watershed and its influence on boulder transport . 419
VI. Vertical distribution of boulders relatively to the parent mass . 421
VII. The crossing of striæ 422
III. The discordance between the directions of the several sets of striæ to be seen on the boulders of Lancashire and Cheshire . 424
IX. The fauna of the drift in the western area of England and Wales 425
X. The physical position of the high-level shell bed at Moel Tryfaen 431
XI. The glacial geology of the Isle of Man 433

APPENDIX B

Field notes in Switzerland, Italy, South Germany, Belgium, and Holland 435

LIST OF ILLUSTRATIONS

PAGE
KETLEY lvi
SECTION OF KETLEY SAND-PIT lix
FRANKLEY HILL lxviii
ROMSLEY HILL lxix
CALIFORNIA lxxi
BOULDER OF POTTSVILLE CONGLOMERATE ON PENOBSCOT KNOB, LUZERNE COUNTY, PENNSYLVANIA 37
LARGE EXTRA-MORAINIC LAKE IN NORTH AMERICA 54
GLACIAL STRIÆ IN PENNSYLVANIA 76
TRACING TO SHOW DIRECTION OF MOVEMENT *up* A SURFACE TO THE SOUTH NEAR GLENGARRIFF 85
GLACIAL STRIÆ NEAR GLENGARRIFF 86
LATERAL MORAINE OF GLACIER AT THE GAP OF DUNLOE 88
EXTINCT GLACIER, NORTH SIDE OF CONNOR HILL, DINGLE . . . 91
SHAPE OF STRIÆ ON ROCHES MOUTONNÉES 92
DIRECTION OF ICE MOTION, AS SHOWN BY STRIÆ ON CONNOR HILL, DINGLE 93
GLACIAL SCRATCH ON CONNOR HILL, DINGLE 94
PARALLEL LINES OF PEBBLES ARRANGED BY WAVES, ONE MILE SOUTH OF MALIN TOWN 113
GLACIAL GROOVE ON ROCK, ONE MILE SOUTH OF MALIN TOWN . . 114
DRUMLIN, SOUTH OF TUBBER 117
GLACIAL STRIÆ AT KILKEE 120
SECTION OF OBLIQUELY STRATIFIED SAND AND GRAVEL WEST OF CAHER. 121
GLACIER SCRATCH NEAR ADARE. 126
GLACIAL SCRATCHES NEAR ADARE 126
SECTION OF DRIFT WEST OF KILUMNEY STATION, COUNTY CORK . . 136
SECTION OF SAND NEAR RAILWAY STATION, CORK 137
BANDS OF STONES AND SHELLS ON TILL RAISED BEACH (HOWTH) . . 150
SECTION OF RAISED BEACH WITH BANDS OF STONES AND SHELLS ON TILL (HOWTH) 151
ARTIFICIAL SECTION, LIMESTONE TILL, NORTH SIDE HOWTH ISLAND. . 152
SECTION OF SAND, BENTON QUARRY, NEWCASTLE-ON-TYNE 171
MORAINE OF NORTH SEA GLACIER AT SPEETON, ON NORTH SIDE OF FLAMBOROUGH HEAD, YORKSHIRE (LOOKING OUT TO SEA) . . . 207

PAGE
Exaggerated Section of Moraine on Flamborough Cliff . . . 212
Moraine at Beacon Hill 213
Brickfield at Driffield 217
Section of Sea-Beach, called Craike Hill, West of Driffield . 220
Quartz Pebble with a Sand Tail 242
Moraine on North Side of Swineshaw Valley. 261
Section of Clay, Moorhey Brickfield, Great Crosby . . . 290
Cuttings in Red Gravel, Weston-on-Trent, Seventy-four Feet above the River 316
Depth of Submergence in the Early and Middle Pleistocene Eras 318
Section of Clay in Hack's Sandpit, West of Leicester Abbey . 322
Section of contorted Sand-bed, Hack's Pit, West of Leicester Abbey 323
Section of Sand in Hack's Pit, West of Leicester Abbey . . 324
Section of Sand in Hack's Pit, West of Leicester Abbey . . 324
Blocks in Pennine Clay, Hack's Pit, West of Leicester Abbey . 325
Worm Burrows in Sand in Hack's Pit, West of Leicester Abbey. 325
Section of Sand at Aylestone, near Leicester 326
Section of Great Chalky Boulder Clay, near Blaby Wharf . . 327
Junction of Pennine Clay and Chalky Boulder Clay, over Sand 328
Roswell Clay Pit, near Ely 335
Diagram showing different Levels of the Ancient and Present Beds of the Delaware River 374
Scratched Boulder at Levenshulme 395
Boulder Clay, crushed contact. Ship Canal, Malley Common Section . . . , ... 399
Section on North Bank of Ship Canal at Malley Common. . . 399
Section on the Manchester Ship Canal, 200 Yards West of Bell House Lane Bridge 400
Section of Boulder Clay and Sand near Bell House Lane Bridge. 402
Section at Pool Hall, near Ellesmere Port. 403
Section at Old-Lock House on Stickins Island, below Barton . 404
Grit forming Base of Permian Marl. The Surface is Ice-scratched. 409
Section of Railway Cutting near Fallowfield, Manchester . . 409
Moraine at Somma Campagna 438
Sketch of Striæ on Rock and Boulders, Grindelwald Glacier . 442
Striæ at Grindelwald 442
Striæ on up surfaces 442
Boulder showing Lee and Stress Sides 443
Furrow in Ice-cave in Grindelwald Glacier 443

PAGE
Upward Motion of Layers of Sand in Grindelwald Glacier . . 444
Diagram showing Lines of Sand in the Glacier abutting against the Moraine 444
Percussion Cones on Glacial Boulder 445
Lines of Stratification in Lateral Moraine, Grindelwald Glacier . 446
Sketch showing Dip of Blue Bands in the Ice 446
Diagram showing Water between a Glacier and the Shore Moraine. 447
Section of a Glacier, with Lateral Streams 448
Sketch showing the Formation of a Medial Moraine . . . 448
Section of a Glacier showing the Concentric Layers of Ice . . 449
Cross and Longitudinal Sections of a Glacier, showing Concentric Bands 450
Section showing the Dipping of the Blue Bands 450
Stone on a Pedestal of Ice 450
Sketch of Ascending Striæ 452
Section showing the Formation of a Moraine Lake . . . 454
Sketch of Medial Moraine joining End Moraine 456
Section of Moraine, near Gümlingen Station 457
Sketch showing Stratification of Sand and Gravel *down* Stream at an angle of 30°. 459
Sketch showing individual Pebbles inclining *up* Stream . . 459
Medial Moraine, moulded into the form of a Drumlin . . . 462

MAPS

TO FACE PAGE
I. Glacial Map of North America 4
II. British Isles, showing Lines of Ice Flow 7
III. Glacial Map of England and Wales 26
IV. Extra-Morainic Lakes of England 56
V. Ireland (Professor Lewis' Routes &c.) 83
VI. England and Wales (Professor Lewis' Routes) . . . 167
VII. North Yorkshire and East Lancashire. 188
VIII. Manchester and Vicinity . . . . , . 256
IX. South Lancashire and Cheshire 291
X. Environs of Birmingham 293

INTRODUCTION

I HAVE undertaken the task of preparing for the press the late Professor Carvill Lewis' manuscript papers and notes on the Glacial Geology of Great Britain and Ireland, in compliance with the request touchingly conveyed to me by Mrs. Lewis in a letter written after his lamented death on July 21, 1888. Notwithstanding its personal references, I shall be pardoned for extracting the following passage from this letter: 'When on July 16 last my husband, Professor Carvill Lewis, first learned the true nature and precariousness of the malady from which he was then suffering, he had a little quiet talk with me as to what should be done with his unfinished manuscripts in the event of its terminating unfavourably. After speaking of those connected with his studies in America, he said with much feeling, "All the papers and drawings relating to my last and best work upon the Glacial Phenomena of Great Britain you must give to my true friend, Dr. Crosskey, with my warm and parting greeting, asking him to arrange, criticise, and edit them for me, should his strength and time permit."'

Although feeling acutely my incompetence, my deep affection for my friend rendered it impossible for me to decline to fulfil his parting wish.

The very making of the request, moreover, was an act of characteristic chivalry to which I could not but respond. We had held many discussions, in the course of which I had expressed doubts as to the soundness of some of his most dearly-cherished conclusions, and yet he entrusted me with his papers with full liberty to treat them as I might choose. Such a mark of confidence rendered his desire a command.

I must, however, venture to set aside the injunction laid upon me to 'criticise' as well as arrange and edit. In the first place, Professor Lewis' own opinions and the grounds upon which he held them are the matters of supremest importance; and, in the second place, he states his case so powerfully as to render a further investigation of the debatable points at issue absolutely unnecessary.

The materials placed at my disposal are:—

1. Manuscript of a paper on *The Direction of Glaciation as ascertained by the Form of the Striæ*, of which an abstract is printed in the *Report of the British Association for the Advancement of Science*, Aberdeen, 1885, pp. 1019–20.

2. Manuscript of a paper entitled *Comparative Studies upon the Glaciation of North America, Great Britain, and Ireland*, of which an abstract is printed in *Rep. Brit. Assoc. Adv. Science*, Birmingham, 1886, pp. 632–5; *Geol. Mag.*, 3, iv. pp. 28–32, January, 1887; *Nature*, vol. xxxv. pp. 89–91, November 25, 1886; *American Naturalist*, vol. xx. pp. 910-25, November 1886; *American Journal of Science*, 3rd series, vol. xxxii. pp. 433–8, December 1886.

3. Manuscript of a paper on *The Terminal Moraines of the Great Glaciers of England*, of which an abstract is printed in *Rep. Brit. Assoc. Adv. Science*, Manchester, 1887, pp. 691–2; *Nature*, vol. xxxvi. p. 573, October 13, 1887; *American Journal of Science*, third series, vol. xxxiv. pp. 492-3, November 1887.

4. Manuscript of a paper *On some important Extra-*

Morainic Lakes in Central England, North America, and elsewhere, during the period of maximum glaciation, and on the origin of Extra-Morainic Boulder Clay, of which an abstract is printed in *Rep. Brit. Assoc. Adv. Science,* Manchester, 1887, pp. 692-3; *Geol. Mag.* 3, iv. pp. 515-17, November, 1887; *Nature* xxxiv. p. 578.

5. Manuscript Field Note-Books. Volumes containing the notes made on the spot at the various places he visited in England, Wales, and Ireland during the years 1885-86 and 87, together with what may be called memoranda of his thoughts and opinions; references to the literature on the subject; and abstracts of many of the papers that attracted his special notice.

6. Maps of his routes and of what he regarded as the glaciated areas.

The second of these manuscripts—that of the Birmingham paper—is in a very rough condition. It is rather a collection of notes for a paper than the manuscript of a paper. I have printed nothing that he did not say, although unable to include *all* that he said.

The manuscripts of the other papers are fairly complete, though altogether unrevised.

The *Field Note-Books* are precisely in the state implied by their name. They are often scarcely legible, and to decipher them has been a task involving no slight amount of labour.[1]

The arrangement of the material contained in them has been equally difficult; and I shall explain, when I have occasion to give extracts from them, the way in which they have been treated.

---

[1] I have to acknowledge the valuable assistance given me by Mr. W Jerome Harrison, F.G.S., of Birmingham, who spent upon these books many days of patient toil.

The maps are as unrevised as the papers. Those given, however, will, it is hoped, suffice to indicate the general course of his researches, although they must not be taken as representing their results in a final form.

Taken as a whole, Professor Lewis' papers, note-books, and maps treating of the glacial epoch in Great Britain and Ireland must be described as containing the history of a series of extensive and original, but, unfortunately for science, uncompleted investigations, and not as constituting a finished treatise on glacial geology. They record the phenomena he observed, the theories he *tentatively* formed from time to time for the purpose of grouping the facts together, and giving direction to his studies; the grounds on which one theory was abandoned, and another put to the test, very probably to be discarded in its turn as 'fresh fields and pastures new' were visited.

Professor Lewis himself would not have published this volume as it now stands. One great purpose, indeed, of his last journey to England, so tragically brought to a termination by his death, was to re-examine all the ground he had traversed, and it was only after such a re-examination had been made that he intended to send to the press an account of his work.

Even the papers read before the Geological Section of the British Association were to some extent 'trial' papers; that is to say, papers in which his opinions were submitted for the criticism of his brother geologists in the same way that they would subsequently have been submitted to his own severer criticism before publication in any completed form. It is within my knowledge that, after the discussion that took place at the Manchester meeting, he abandoned his intention of reading a paper on the subject before the

Geological Society of London, in order that he might gain time for further explorations.

It will be evident, therefore, that Professor Lewis' researches had a wider range and a deeper meaning, and would have ultimately led to more important results than can be at all adequately understood from the fragmentary and imperfect records of them that have been preserved.

His completed investigations would have thrown light upon his tentative speculations; and the wisdom with which he selected the many paths he traversed, would have become more fully apparent had he been spared to follow them out to the end of their winding and intersecting courses.

No apology, however, is needed for the publication of this volume. The scientific acquirements of Professor Lewis were so remarkable; the energy with which he devoted himself to his geological pursuits was so unconquerable; the extent of country, alike in America, Europe, Great Britain, and Ireland, over which he travelled was so exceptionally large; he united such powers of generalisation with minute accuracy of observation; and he was so little bound by conventional opinions; that the history of his studies cannot but be full of instruction, and furnish materials of large value for other investigators of the complicated phenomena of the glacial epoch.

I may with advantage introduce at this point some notes furnished me by Mrs. Lewis, who was the constant companion of her husband, both in the field and in the study. Some portions of these notes, it is true, relate to subjects which do not belong to glacial geology; but the connected account they give of Professor Lewis' scientific career shows so clearly how he was induced to undertake the examination of its problems, and how thoroughly he was prepared to confront them, while they throw such a bright light upon the spirit in which he pursued all his studies, and at the same time describe so plainly the successive stages through which his glacial inquiries themselves passed, that I print them without alteration or comment precisely in the form in which they were received.

NOTES

Among the many who felt an interest in the geological researches of the late Professor Henry Carvill Lewis, those who knew him best perceived that such ability as he had lay not so much in any special gift for this or that particular branch of scientific investigation, as in the possession of an unusually delicate eye, and the power to describe accurately what he saw, uninfluenced by preconceived opinion.

Indeed, so little did he care for theories, that the writer has on more than one occasion seen him cast aside, without a moment's hesitation, working hypotheses upon which he had spent weeks, or even months, of careful thought, and accept with avidity the ideas of some who had steadily opposed him, so soon as he perceived that the majority of facts had led him on their side of the line. 'Take care of the facts, and the theories will take care of themselves,' was one of his favourite expressions, and how well he followed its teaching will be patent to anyone who has read his *Notes on the Zodiacal Light, Aurora,* &c., written at the beginning of his scientific career, and *Some Alleged Physical Phenomena in Spiritualism*, published shortly before its close.

These two papers, with the others written between them, will show at a glance how varied was the field over which his thoughts and interest ranged. 'This earth is none too large for me,' was his frequent exclamation, and, 'Had I the space of three lives at my command, I could easily fill them with the work that I see before me.' After his departure a distinguished English geologist wrote of him: 'He seemed to belong to no country, but to be a citizen of the world; a link between the workers in far distant lands.'

Integrity of life and mind, and a sound physical constitution, he possessed in common with all his family; but the thirst for knowledge, and the special bent for scientific pursuits, seem to have been inherited from his maternal grandfather, Henry Carvill, Esq., in whom they were marked traits of character, and who delighted to watch their unfolding in his only grandson.

Special mention should also be made of the encouragement given Professor Lewis in his earlier years by his father, F. Mortimer Lewis, Esq., of Philadelphia, who, though his own interests and work for humanity lay in a different channel, no sooner perceived the clear bent of the boy's mind, than he granted him every aid in his scientific studies, taking care, however, to build them upon a firm foundation of general culture.

In the pursuit of his life-work, Professor Lewis was uninfluenced by personal motives, and worldly advantages seem to have had for him no attraction whatever. In the last note-book which he carried was found the quotation from Socrates: 'Choose knowledge rather than wealth; for while the one is transitory, the other is perpetual.'

Professor G. F. Wright, who was closely associated with him in his glacial studies, remarks: 'In all his researches, Carvill Lewis was stimulated by the thought that man does not live by bread alone, but that he who ministers to the mental wants of the race by discovering truth and bringing it within reach of the general apprehension, is as truly a philanthropist as he who adds to their bodily comforts.'

His general mental characteristics, and the nature of the special qualifications he possessed for the study of the glacial phenomena of Great Britain and Ireland, the subject of which this volume treats, will be seen on referring to his earlier scientific work, and to the prolonged, laborious, and thoughtful investigations which he carried on for the purpose of solving, if possible, the problems connected with the glacial geology of North America.

During the later years of his college life, and the earlier ones of his scientific career—from 1874 to 1879—his attention was divided almost equally between astronomy and geology. His work in the former science consisted chiefly of varied observations, comprising photometric measurements and position maps, of the zodiacal light, band, and 'Gegenschein,' and of the phenomena accompanying a number of brilliant auroral displays.

The existence of the zodiacal cone proper was admitted by astronomers in general, but a number of observers, both past and present, regarded that of the 'Band' and the 'Gegenschein' as decidedly chimerical.

In order to cut the Gordian knot of this interesting question, Mr. Lewis made a long series of observations, extending over several years, and, lest the wish should prove father to the conclusion, carefully refrained from ascertaining the position of the Sun in Right Ascension until the time appointed by himself had expired. It was then found upon calculating the Sun's position in each case, that the map which he had made was correct; as, if the Gegenschein existed at all, it should have been visible precisely at the successive points where he had described it.

Among the astronomers who, through this paper, were led to feel a lively interest in Mr. Lewis' researches was Professor Simon Newcomb, who afterward made several efforts to persuade him to devote himself wholly to astronomical work.

It is probable that the extreme delicacy of vision and accuracy of definition, which were among Professor Lewis' more marked characteristics, were largely developed by his astronomical investigations, and they proved valuable aids in his later studies in geology and mineralogy.

But astronomy was unable to claim more than a small portion of the absorbing interest which he felt in the problems of the world around him, and a little later he slowly gravitated towards geology and mineralogy as offering a more comprehensive field for the main work of his life.

The earliest scientific publication on record by H. Carvill Lewis is a paper on *Strontianite and Associated Minerals in Mifflin County, Pa.*, read before the Academy of Natural Sciences, Philadelphia, in 1876; but others followed in rapid succession, and in the *Proceedings* of that body between 1877 and 1880, we have notes of at least twenty-nine communications on a variety of geological and mineralogical subjects.

In 1878 and 1879 he was busily studying the surface geology of South-Eastern Pennsylvania, and particularly the large gravel deposits of the Delaware river. The results of this work are contained in a paper entitled: *The Trenton Gravel, and its Relation to the Antiquity of Man*, read before the Academy of Natural Sciences, Philadelphia, November 24, 1879; and in a longer article on *The Antiquity and*

Origin of the Trenton Gravels, written as an appendix to a work on *Primitive Industry*, by Charles C. Abbott, M.D., published in 1881.

From the former paper it may be learned that his interest in glacial geology was already wide awake, though the decision to devote himself to that special line of research was not made till the latter part of 1880. When he did make this decision, his principal reason for doing so was to determine, if possible, the approximate date of the disappearance of the ice-sheet, in the hope of throwing light upon the length of time required to raise man from a primordial type to his present state of physical and intellectual development.

On referring to p. 25 of the paper on *The Trenton Gravel, &c.*, we find that Professor Lewis at first held rather with observers who believe in the existence of *two* glacial epochs, separated by a long interval of time, than with those who think that the evidence thus far obtained is in favour of there having been but *one*.

This view was afterwards changed, as he himself stated, 'solely by the fact that he had been unable to discover the smallest trace of glacial action[1] south of the line of the Terminal Moraine in Pennsylvania' (see pp. 44 and 45 'Report Z,' by H. Carvill Lewis; also *Supposed Glaciation in Pennsylvania South of the Terminal Moraine*), or of the separate or coalescing glaciers of England, Wales, and Ireland (see abstracts of papers read before the British Association in Manchester, September 1887, on *The Terminal Moraines of the Great Glaciers of England*, and *On Some Important Extra-Morainic Lakes, &c.*). In Professor Lewis' own words, 'The first unmistakable evidence which he found of a prior period of glaciation, either in America or Great Britain, was in October 1887, when, in company with the Rev. Dr. Crosskey, he made a critical examination of the deposit on the summit of Frankley Hill.'

---

[1] Namely, of *solid ice* action.

This locality, by a mere accident, was the only one where 'till' was reported to occur south of the terminal moraine line, which he had not personally examined before presenting his paper on the subject to the British Association, in Manchester. (See paper *On Some Important Extra-Morainic Lakes &c.*)

During the meeting of the American Association, in Boston, in August 1880, the papers read by Mr. Lewis, entitled, *Notes on the Zodiacal Light, Notes on the Zodiacal Light and Aurora of May* 2, 1877, *The Iron Ores of the Brandon Period,* and *The Antiquity of Man in Eastern America, Geologically Considered,* caused his immediate elevation from the rank of a 'Member' to that of a 'Fellow' of the Association.

The address upon *The Antiquity of Man &c.* was followed by a long discussion of that and glacial matters in general, and at its close a gentleman in clerical dress crossed the room, seated himself near Mr. Lewis, and after expressing much pleasure in what he had heard, suggested that Mr. Lewis should accompany him to Andover, Mass., and investigate some fine kames in that neighbourhood.

The acceptance of that invitation changed the whole course of Mr. Lewis' life, and before he returned to Philadelphia the Rev. George Frederic Wright had so interested him in the great questions connected with the Glacial Epoch, that the following years of work, both in America and Great Britain, were but the ever-widening result of those few days spent in Andover.

About two months later, Messrs. Lewis and Wright together examined the gravel beds at Trenton, and the drift in the neighbourhood of New Haven, Connecticut, under the guidance of Professor Dana.

By this time both geologists were convinced that the phenomena studied at the north were due to the action of *land-ice only*, and being satisfied that the line of drift hills traced by Mr. Warren Upham across Block and Long Islands, and by Professors Cook and Smock in New Jersey, was a genuine moraine, they determined to follow the line from Belvedere, New Jersey, to some little distance in Pennsylvania, and, if their surmise proved correct, to organise a more extended campaign for the following summer.

In December, 1880, the preliminary study of the country lying between Belvedere, New Jersey, and the Delaware Water Gap was made, with satisfactory results, and in the early part of 1881 the State Survey of Pennsylvania accepted Professors Carvill Lewis' and Wright's proffered services, and gave them every facility for the prosecution of their work. The tracing of the entire terminal moraine of that portion of the great ice-sheet which entered Pennsylvania was done between June and September 1881, two-thirds of the distance being traversed by Professor Lewis alone (with the exception of a tract lying in Central Lycoming and Southern Venango counties which was traced by Professor Wright), while during the remaining third he had the pleasure of Professor Wright's aid and companionship. The result of this six months' work is given in 'Report Z' of the second Geological Survey of Pennsylvania.

The only views therein expressed which Professor Lewis later found reason to alter were those in connection with the 'fringe,' as he named the irregular patches of drift found south of the moraine in the western portion of the State. (See paper entitled *The Great Terminal Moraine across Pennsylvania*, p. 12; also abstract of Manchester British Association paper on *Some Important Extra-Morainic Lakes &c.*)

The first public announcement of Professor Lewis' work on the Pennsylvania moraine was made at the Montreal meeting of the American Association in August 1882.

Among the geologists then present were Sir William Dawson, Dr. T. Sterry Hunt, Professors Hall, Newberry, and Julien, of New York, Cook, of New Jersey, Coxe, of Indiana, Professor Winchell, Dr. Spencer, and many others, from all parts of the United States and Canada.

An animated discussion followed Professor Lewis' paper, during which a few of the audience concurred in his views; but the greater number steadily opposed him, believing that the phenomena which he described were produced by a marine submergence with floating bergs carried down from the Greenland ice by a strong south-westerly current.

In answering his opponents Professor Lewis stated that, while their theory was undoubtedly correct for the deposits of the Champlain and Laurentian basins—where the ice was interrupted by sea water which then filled these two great depressions—it did not hold good for the country lying either to the north or the south of them, which was covered by a sheet of solid ice several thousand feet thick.

Two years later, in August 1884, Professor Lewis delivered an address before the British Association in Montreal, on '*Marginal Kames*,' and in the following October he published a pamphlet on *Supposed Evidences of Glaciation in Pennsylvania, South of the Terminal Moraine*, which brought his active connection with American Glacial Geology to a close; though there still remain a number of more or less valuable observations on this subject which it is hoped will shortly see the light.

The exact relation which the detailed study of the glacial phenomena of Pennsylvania bore to the solution of this great problem for the country at large has been well described in 'Report Z,' p. 15, where the author remarks: 'Pennsylvania happens to be most fortunately placed for the elucidation of the many problems of the great ice-age. Occupying a middle position between the glaciated and the non-glaciated regions of this country, and between the well-studied glacial phenomena of New England and the imperfectly understood surface deposits of the West, and being traversed by the whole Appalachian range of mountains lying transversely to the ice flow, this state, so remarkable for its varied topographical features, is a typical region for the study of the Northern Drift, and offers unexampled facilities for laying true foundations for the science. Nowhere in the world has the great glacier come to an end and pushed out its terminal moraine under more varying conditions. From the lowlands of the Atlantic coast, to the mountain plateau of the Alleghanies, and down again toward the great plains of the Mississippi basin, the line can be traced, step by step, without a break, marking the extreme edge of the ice-sheet. Rivers flow out from the glacier, rivers flow back under it, and other rivers take their source south of it, and have their distinctive accompanying phenomena, full of interest and instruction. As from its industrial and political standpoint, so from its position in relation to the great glacier, Pennsylvania is indeed the "keystone State."'

WORK IN GREAT BRITAIN

Both before and during his investigation of the glacial deposits of Pennsylvania, the attention of Professor Carvill Lewis was naturally drawn to the observations of other workers both in Europe and America; but the more familiar he grew with the writings of British geologists upon the drift of their own islands, the more puzzled and interested he became. That during the present century no less than two thousand or more publications, large and small, should have been issued by British observers—many of whom ranked among the most gifted geologists of the world—and yet that the testimony of scarcely any two of them should agree together—seemed to him after his experiences in Pennsylvania, well nigh incredible; and it was not long after the final chapters of 'Report Z' were written that first the wish, and then the determination, to cross the sea and settle this alluring problem for himself, took definite shape in his mind.

'Report Z' was transmitted to Professor J. P. Lesley, State Geologist of Pennsylvania, in October 1882, and in May 1884 Professor Lewis had decided that, should circumstances permit, he would begin work in Ireland in the following year.

During the intervening twelve months he made himself familiar with the work already accomplished by British geologists, and from the mass of nearly irreconcilable material before him made notes of the opinions and observations which seemed best to harmonise with what he had observed in America. That he did succeed in gaining a tolerably firm grasp of the situation may be inferred from a remark of the late Mr. S. A. Adamson, of

Leeds, in a letter to Professor Lewis (now in possession of the writer), in which he said: 'You know more than nine out of every ten of our own geologists.'

Professor Lewis' first impression, derived from the works of leading British authorities, was that Ireland had probably been covered by a homogeneous sheet of ice, which had moved down from Scotland, north-east to south west, and that if a moraine had been formed at all, it would be found between Arklow and the valley of the Lee.

He arrived at Cork in June 1885, and was interested to find large quantities of water-borne drift in the Cork valley and on the islands lying in the harbour; but a fortnight later, on examining the Macgillicuddy Reeks, he saw that, whatever might be true of the north, here was a small centre of local but heavy glaciation, the ice having been from 700 to 800 feet thick, where it passed off to sea at the mouth of Kenmare Bay.

So circumscribed, however, was the area it covered, that the island of Valentia, though lying at the foot of the Reeks in Dingle Bay, showed no trace of glacial action whatever, save some water-carried boulders, which were sprinkled about on the surface of the island as plums over a pudding.

The Dingle Mountains proved even more interesting than the Reeks, from the number of miniature moraines with small pools that did duty as 'intra-morainic lakes,' found upon them.

Some of the ice-streams issuing from the cup-shaped basins on the hills above were so small that the bed over which they had passed could be spanned by the outstretched arms of two persons standing side by side, and yet the striæ made on the contiguous rocks were as sharply cut as if done by the wheel of a lapidary. The writer has in several instances spanned with one hand portions of rock, *in situ*, where there was every mark of typical glaciation covered by the little finger, and of equally typical non-glaciation covered by the thumb.

None of the glaciers on the Dingle Mountains coalesced, and the amateur geologist can find no better spot for studying the special characters of extinct glacial phenomena than this interesting region.

On more extended excursions north of the Reeks and Dingle Mountains, a band of non-glaciated country was found lying between them and the mountains of Clare and Connemara on the north, and the Commeragh Mountains on the east.

The centre of Ireland was covered by an ice-sheet formed by the united streams from the Clare and Connemara Mountains on the west, the Donegal Mountains and the Scotch ice on the north, and the Wicklow Mountains on the east. The Commeragh Mountains also formed another local ice centre for south-east Ireland. Owing to the complicated nature of the deposits lying between the Wicklow and Commeragh Mountains, and from thence to the sea, it was Professor Lewis' intention to go carefully over that region again (he examined the country between Cork and Mallow no less than six times) in order to verify his conclusions with regard to their several origins.

The finest kames, or drumlins, and lateral and medial moraines observed were in the north, between Belfast and Omagh, where the Scotch ice flowing south-west, and the Donegal ice flowing east and south-east, coalesced and ground up everything between them.

The only kame as yet seen in England by the writer which will compare in size with those observed in north-east Ireland is the one just behind the railway station at Durham, upon which a large pleasure garden has been laid out; the irregularities of its surface having been turned into charming effects by the skill of the landscape gardener.

In this corner of England the same conditions exist as in north-east Ireland; for the large stream of ice coming down from the north and passing off to sea was pressed back by the Scandinavian ice, as the Donegal sheet was by the Scotch ice.

One of the most valuable aids in Professor Lewis' work in Ireland were the detailed observations of the Rev. Maxwell H. Close, M.R.I.A., &c., every one of which was found to be absolutely correct.

He also received generous and important assistance from Professor E. Hull, LL.D., M.R.I.A., &c., Mr. G. H. Kinahan, M.R.I.A., F.G.S., &c., and many others, and it was his intention to return special thanks to each of these gentlemen in the Preface of his Report.

The maps showing the general results of Professor Lewis' studies in both Ireland and England were, as he himself stated, 'Merely sketch maps, which would probably require a number of future modifications as his knowledge of the two countries improved by repeated examination of their surfaces.'

Having seen that the main ice-sheet of Ireland was composed of streams issuing from five distinct local centres, while the glaciers from the Reeks and the Dingle Mountains evidently never united with each other or with those from the north or the east, Professor Lewis was prepared to find a corresponding series of phenomena in England. His subsequent observations proved this idea to be well founded, and having carefully examined all but one of the areas reported as showing the unmistakable action of land-ice, his opinions underwent few changes worth noting until he came to the last of these localities, the patch of drift on the summit of Frankley Hill, which was critically examined in the presence of the Rev. Dr. H. W. Crosskey.

The study of a new cutting in the deposits at California, made a few days later in company with the same authority, confirmed the impression gained at Frankley Hill, and it was his intention to re-survey all the drift-covered areas of England lest a similar deposit elsewhere might possibly have escaped his notice. From the nature of the drift on Frankley Hill, and from the direction of the trail of scattered boulders of Arenig rock lying between that point and the Welsh frontier, Professor Lewis felt convinced that here were the genuine traces of '*a very ancient glacier*,'[1] between which and the phenomena he had just been studying as vast an interval of time had elapsed as between those of the great glacial epoch and the present day.

The most difficult portions of the terminal moraine to trace were those lying in Lancashire, where a considerable submergence had taken place during the close of the glacial period, and where the drift had been formed under the sea-water, and had been washed about by it, and that crossing Yorkshire, where the phenomena were of an unusual and complicated nature.

Of the Yorkshire drift, Professor Lewis said in a letter to the writer, dated August 23, 1886: 'Day and night I have been rushing over the land in search of the truth.

---

[1] See p. 69 of this vol.

The moraine for a time baffled all endeavours, and after going again to Whitby, then to Hartlepool, Darlington, Richmond, &c., I was more in the dark than ever, until all at once one evening light broke, and the problem was solved. A long drive yesterday proved my theory and all is now clear. *Two* great glaciers came out of the mountains, disconnected with one another and having an unglaciated area between—an idea quite new. I found drift at one place, then to the north of it none, and again farther north more drift, all inexplicable at first, but now all plain. Two days more work and I have done.'

The broken shells found with glacial drift on the summits of Moel Tryfaen and Three Rock Mountain, where the ice had moved on to the land from the sea, were not at all surprising to an observer acquainted with such facts as described in 'Report Z,' p. 106, where we find it stated: 'At 2,088 (by aneroid) the author found a fine transported boulder of white Pottsville conglomerate, measuring 9 × 6 × 4½ feet. It rests upon an outcrop of Catskill sandstone, hundreds of feet higher than any outcrop of the conglomerates around the Wyoming coal basin.'

On p. 14, 'Report Z,' is the remark: 'Evidently it' (the ice) 'must have been 2,500 feet thick to flow over Penobscot Knob' (the mountain on whose summit the boulder in question rests), 'and eight miles further south, to the terminal moraine in the Conyngham Valley.' (See also *The Ice Age in North America*, p. 401, and Mr. Warren Upham's paper, *Marine Shells and Fragments of Shells in the Till near Boston*.)

In *The Building of the British Isles*, the writer, Mr. A. J. Jukes-Brown, remarks (p. 281): 'He' (Mr. J. G. Goodchild) 'relies on the fact that both glacier-ice and polar-ice are more or less dirty, and on J. D. Forbes' observation that the lower layers of glacier-ice work *up* toward the surface as the whole moves onward. He naturally infers that the rock detritus does not remain at the bottom of the moving ice, but that the whole mass becomes charged with the products of erosion, both in the form of mud and of stones and boulders.' Further on Mr. Jukes-Brown says: 'Mr. Goodchild only applies this hypothesis to the drifts of mountain districts, and does not seem to have considered what might take place in those areas where the ice had usurped the place of the sea. Indeed, he is needlessly sceptical about the submergence which even the most extreme glacialists are prepared to admit; but it would probably repay anyone who was studying an area where marine drifts abut against a mountain district to consider whether some modification of Mr. Goodchild's hypothesis would not explain the intercalation of marine sands and shelly boulder clays.' (See *Quart. Journ. Geol. Soc.*, vol. xxx. p. 320; also vol. xxxi. p. 55; *Geol. Mag.*, December 2, vol. i. p. 496, and *Trans. Cumb. and Westm. Assoc.*, 1887, No. xi. p. 111.)

Professor Lewis' observation of the lines of upward moving drift in the Grindelwald glacier, and his application of the facts derived therefrom to the deposits on the summits of Moel Tryfaen and Three Rock Mountain contain no new idea, and to American geologists at least will appear the most likely solution of this interesting problem.

Professor Lewis was fully convinced that the West of England had been submerged to some depth during the close of the glacial period; but the tracing of the exact limit reached by the sea, and the careful mapping of the basins occupied by the inter- and extra-morainic lakes, and the many large glacial drainage streams, he laid aside as work to be done when all the deposits due to the action of land-ice *alone* had been carefully studied and recorded.

Had Professor Carvill Lewis been permitted to continue his investigations, he intended sparing neither time nor labour upon the task of deciphering the glacial deposits of Great Britain. In the prosecution of his researches he was devoid of the wish to prove theories or conjectures of any kind, he had no personal ends to be gained by them, and the ruling motive which inspired him in this, as in all else that he did, was to spend and be spent in the effort to make the world 'a little wiser, a little better, and a little happier' than he found it. How well he succeeded in this endeavour let those who knew him, both in the Old and the New World, answer.

JULIA F. LEWIS.

As I have already stated, I regard it to be my duty as editor to present to geologists the observations and opinions of Professor Lewis himself in the best way that the state of his manuscripts permits, and not to discuss them from any point of view of my own.

Some slight assistance, however, towards the full understanding of what these observations and opinions were, may be given if I venture to gather together what appear to me to be some of the most salient and notable of the many questions in glacial geology to which the papers and notes published in this volume directly refer.

I

Glacial geology has suffered from the fact that comparatively few have personally studied its phenomena over a sufficiently large area. An exceptionally large proportion of the papers published upon it consist of more or less minute descriptions of what occurs in particular localities. Large generalisations have been frequently made from these descriptions; and it has been too frequently assumed that deposits which may be due to local circumstances are of universal range.

The terms in use among glacial geologists, moreover, are extremely vague; one writer, for example, employing such an important term as 'boulder clay' in one sense and another in a sense entirely different.

It is, perhaps, more necessary in glacial geology than in any other branch of geological science, that whoever propounds a theory should see for himself at any rate the principal sections upon which he relies for its establishment and defence.

Professor Lewis travelled through Great Britain and Ireland, and through Switzerland, after having thoroughly examined a vast district in America, and his comparative studies of the glaciation of the various districts and countries he visited deserve, therefore, special attention.

Whether or not his conclusions be finally established, his comparative method of study is undoubtedly the only one by which the great problems under debate can be adequately solved.

II

In glacial geology, not only what the facts mean, but *what they are*, is a subject of constant discussion. The sections in clay pits, embankments, and railway cuttings are so frequently destroyed soon after their first exposure, and are often so variable along the same lines of excavation, that one geologist not unseldom sees what is hidden at the visit of another.

There is so much scope for speculation also in the whole subject, and the sections are so capable of being read in different ways, that the holders of antagonistic theories may not describe them in precisely the same terms, although they may be equally desirous of representing 'things as they are.'

What may be called the faculty of being accurate was, however, so marked a characteristic of Professor Lewis' mind that a large collection of facts will be found in his writings which must be respected, whatever account be given of the history of the glacial epoch.

It will also, I think, be generally admitted that he has corrected some errors which have obtained a wide circulation. In illustration of this I may allude to one point of considerable importance in British glacial geology.

The various deposits denoted by the general name of 'drift' have been arranged in three great divisions, viz., Upper Boulder Clay; Middle Sands and Gravels; Lower Boulder Clay.

Professor Lewis was by no means convinced that this threefold division can be established, and indeed positively states that even in England the deposits of the 'drift' are anything but constant in succession.

Since he wrote, this observation has been entirely confirmed in the very district to which, as will be seen in his Field Notes, he appeals for the justification of his suspicions. In a paper by Mr. J. W. Gray, F.G.S., *On the Glacial Geology of Stockport*, a number of sections furnished by the proprietors of deep wells in that town have been recently published,[1] which show clearly that no threefold division of the drift will suffice. I quote some examples of these sections, all of which, it must be noted, extend to about the same depth, and stand almost at the same level above the sea.

BROOK STREET, HIGHER HILLGATE

O. D. 254 feet

	Feet
Sand and gravel	28
Quicksand	30
Clay with boulders	34
Gravel and boulders	10
	120

MOTTRAM STREET

O. D. 250 feet

	Feet
Sand	39
Fine clay	1
Clay	8
Boulder clay	8
Sand (dry)	5
Gravel	8
Red sand and fine clay	7
Brown sand and pebbles	1
Red sand and fine clay	5
Red sand and boulders	10
	92

EDGELEY (NEAR JAMES STREET)

O. D. 239 feet

	Feet
Boulder clay (with seams of sand and fragments of shells)	40
Stony clay	8
Fine clay, no boulders	16
Boulder clay	6
Gravel and boulders	20
	90

---

[1] See *Stockport Society of Naturalists' Annual Reports*, 1887–8, p. 50.

NORTH REDDISH

O. D. 250 feet

	Feet	Inches
Stiff clay	10	0
Stiff sand	10	0
Coarse sand	2	0
Fine sand	23	0
Clay	8	0
'Blue stone' (? boulder)	4	0
Stiff clay	8	5
Clay and gravel	9	5
Gravel	7	0
Loam with boulders	16	5
Clay with boulders	11	5
Stiff clay	7	0
Clay with sand	2	5
Gravel and sand	12	5
Clay with loam	2	0
Running sand (? top of rock)	8	0
	126	6

Further confirmations of Professor Lewis' opinion might readily be quoted.

In his work on *The Building of the British Isles*, Mr. A. J. Jukes-Brown writes, 'The most recent and most detailed observations on the later glacial series of Yorkshire,[1] Lincolnshire,[2] Cheshire,[3] and Lancashire,[4] have shown that the supposed division of these beds into an upper and lower boulder clay, separated by a set of marine sands and gravels, is incorrect, the sands and gravels being only lenticular beds, and occurring at various horizons in the series.'

Professor Lewis may or may not be right in his conclusion that the alternating layers of stratified and unstratified drift are due simply to the deposition of material sometimes by an ice-sheet itself, and at other times by the water circulating under it; but he is evidently right in his statements respecting the facts that need explanation.

---

[1] *Geology of Holderness*, C. Reid, Mem. Geol. Surv. 1886.

[2] *Geology of East Lincolnshire*, 1887, p. 76, and *Quart. Journ. Geol. Soc.* vol. xli. p. 114.

[3] A. Strahan, *Quart. Journ. Geol. Soc.* vol. xlii. p. 369.

[4] Mellard Reade, *Quart. Journ. Geol. Soc.* vol. xxxix. p. 83.

Another service rendered by Professor Lewis in the same direction is that he calls attention to some assumptions which have been regarded as facts. For example, he asks whether the upper and lower boulder clays of the Lancashire drift may not be the same deposit? This again may or may not be the case; but it cannot be *assumed* that they are the same, and the challenge given by Professor Lewis to the supposed fact must be met by further inquiry.

III

Professor Lewis has recognised the importance of many facts which, although established, have not had, in my belief, sufficient weight given to them, and has brought forward a large amount of additional evidence respecting them.

For example, so far as I am able to judge, he has rendered the greatest service to English glacial geology especially, by calling emphatic attention to the *fresh-water origin* of many so-called glacial deposits.

Whether marine submergence has taken place to any vital extent or not, or whether or not there has been a succession of submergences—questions to which allusion will presently be made—large and powerful bodies of fresh water must have issued from beneath any ice sheet or any glaciers, and have left marked traces of their effects; while the whole drainage of the country must have been strongly affected.

Sands and gravels would be deposited in close connection with the boulder clays or any morainic material. Lakes would be formed both within and without the moraines, and although many of them would be temporary by the breaking down of the barriers confining them, torrents would be created, and bear even to long distances masses of débris.

In morainic lakes icebergs would float, carrying from place to place at least *some portion* of the blocks which are the 'erratics' of to-day.

The courses of rivers would be *dammed* by the advancing or retreating ice, and their waters either be driven to seek new channels or be accumulated in large expanses according as the physical geography of the district might determine.

Should the ice in any case have advanced from the sea, in a direction contrary to that of the drainage of the land over which it passed, a peculiar mixture of curiously alternating beds of fresh-water deposits and of clays containing fragments of marine shells would be the result.

The amount of information on these points contained in Professor Lewis' papers places those who may reject and those who may accept the conclusions he draws from the facts under an equal obligation to him.

Those who believe in the theory either of one extensive submergence or of a series of submergences, are as much bound as their opponents to acknowledge to the very fullest extent the work of glacier-fed streams, to search for the beds of glacial lakes and meres, and for the erratics dropped by the bergs floating in their waters; to trace the courses of glacial rivers, and to follow the sweeping rush of torrents.

All these effects of fresh-water action *might* have been produced during and after the re-elevation of the land, *supposing a second glacial epoch to have occurred*, as well as without any marine submergence at all and during one prolonged period of glaciation.

That this is the case, however, rather intensifies than diminishes the signal value of the service Professor Lewis has rendered to all students of glacial geology, by dwelling so emphatically as he does upon the effects of melting ice and the circulation of subglacial waters; and upon the necessity of separating the deposits made by land-ice from those due either to lakes with their icebergs or to torrential waters.

Upon another fact, also I think somewhat neglected in England, Professor Lewis lays marked stress—viz. the existence of non-glaciated areas.

In Pennsylvania, Professor Lewis had noticed a strongly marked contrast between the glaciated and non-glaciated regions, and had found no difficulty in distinguishing their distinctive characteristics. The following passages are taken from his report on the terminal moraine in Pennsylvania and western New York:—

'The writer has explored every river and stream which flows out of the glaciated region, and finds in each case a distinct point of demarcation between the glaciated and unglaciated regions. Sometimes the river shows by its very aspect and rate of motion the influence of glacial agencies, its channel being so filled up with glacial débris as to render its flow sluggish. Still more evident is it in the case of tributary streams, which often flow on rock bottoms in the unglaciated region, while in the glaciated area their channels may be deeply buried under drift. The tributary streams of the Lehigh north of the terminal moraine are in marked contrast to those south of that point; the former flowing through drift-filled ravines with gentle banks, the latter through rocky precipitous gorges.

The Conewango in the glaciated area is a sluggish stream, flowing upon drift and bordered by low gravel banks, while south of the terminal moraine its banks are rocky and steep.[1]

'Notwithstanding the fact that in the narrow gorge of the Lehigh the moraine has been completely washed away, the character of the banks of the river and of the gorges occupied by tributary streams is sufficient to indicate its position. South of the moraine the rocks bordering the picturesque gorge of the Lehigh are bare, or covered with sharp fragments torn off by frost. Pulpit rocks occur at Stony-run.

'The numerous gorges formed by tributary streams contain no gravel and are occupied only by fallen rocks. Thus Leslie's-run and Muddy-run,[2] though but a mile or two below the drift-covered area, enter through gorges perfectly free from drift. Although there are boulders in the river bed, and patches of boulder-bearing clay frequently lie high up on the banks (as high as 180 feet above the stream), these cannot be mistaken for the true glacial drift north of the moraine.

'But entering the glaciated region the character of the river banks is suddenly changed. A covering of gravel and large rounded boulders appears on either side; the drift has filled the gorges occupied by tributary streams and transformed them often into shallow valleys; and terraces and ridges of gravel appear at the bottom of the river valley itself.'[3]

It will be seen in the extracts from the Field Note-

---

[1] 'Report Z,' p. 23.

[2] In American phraseology the term 'run' means a stream larger than a rivulet and smaller than the smallest river.

[3] 'Report Z,' p. 94.

Books that, guided by these experiences, Professor Lewis is always on the look-out, both in England, Wales, and Ireland, for the same kind of distinctions between glaciated and non-glaciated regions which he had observed in America. He often asks 'Are we not in the non-glaciated area?' and although as his journeys are extended he finds reason to shift its boundaries from point to point, yet he clearly has a very decided conviction that those boundaries can be and ought to be traced, and that the dimensions of the great British and Irish glaciers can therefore become known.

He frankly admits that he was at first greatly perplexed by the presence of true glacial deposits—to which he gave the name of 'the fringe'—*outside* the boundaries of what he regarded as, without question, terminal moraines; that is, in regions which, according to the general tenor of his observations, ought properly to be called non-glaciated.

In his Pennsylvania Report he describes deposits of clayey drift, and even clusters of gigantic boulders (some of which must have been brought from a distance of nearly 300 miles) as occurring at places situated far beyond the limit he assigned to the great terminal moraine.

While engaged upon the American Survey, Professor Lewis did not attempt to reconcile the definiteness with which he believed the boundaries of the moraine could be fixed with the presence of these apparent proofs of ice-action in external districts.

Subsequently he came to the conclusion (on grounds which are fully stated in his papers) that the glacial clays, sands, and gravels, together with the erratics which occur outside of a terminal moraine, are due to flowing water and to the ice floating in morainic lakes.

IV

Professor Lewis devoted himself with resolute energy to the determination of the question whether the glacial deposits of Great Britain and Ireland may not be most satisfactorily interpreted by considering them with reference to a series of great terminal moraines; and travelled far and wide in order to discover these moraines, and to trace their courses and define their limits.

As the result he mapped out the great glaciers of the three kingdoms and marked their points of confluence. At the same time he investigated the evidence that remains of the existence of the smaller local glaciers which would necessarily be separately developed during the retreat of the ice.

Glacial geologists of all schools will here again admit the value of the work he has done in these directions.

One great generalisation, however, which he made may become the subject of some controversy.

Professor Lewis maintained that *every glacier*, at the time of its greatest extension, is bounded and limited by a terminal moraine. This proposition he regards as 'a principle' which furnishes the veritable key to glacial geology.

But Dr. G. Frederic Wright, in his great work on *The Ice Age in North America*, states that he has been compelled to abandon this view in its extreme form.

He writes (p. 120): 'When a few years ago attention was first directed by Mr. Clarence King, Mr. Warren Upham, and Professor George H. Cook to the terminal moraines of southern New England and northern New Jersey; by Professor T. C. Chamberlin to the character and connection of the kettle-moraine in Wisconsin; and by

Mr. George M. Dawson to the significance of the extension of the Missouri coteau in British America, hopes were at once raised that a distinct line of terminal moraines might be traced across the continent. With this theory in mind the late Professor H. Carvill Lewis and myself began the survey of Pennsylvania in 1881. But upon crossing the Alleghanies and pursuing the investigations in the Mississippi valley, I was compelled to abandon this view, and to be content with finding marginal deposits more evenly spread over the country, ending in some cases in an extremely attenuated border.'

After remarking that by a terminal moraine is meant 'a noticeable ridge of glacial accumulations to mark the farthest extent of the ice,' Dr. Wright proceeds to state *why* such a noticeable ridge cannot always be found.

'The extent of a glacial deposit at any particular point will be determined by three factors, namely: (1) The amount of accessible loose material in the line of glacial movement which the ice can seize upon and transport. It is evident that, if the rocks over which the ice moves are hard and smooth, and already denuded of loose material, there may be much motion of ice and little transportation of soil. (2) The length of time during which the ice-front remains at a given point, since time acts as a multiplier. (3) The exemption of the deposit from the action of denuding agencies. When a glacier melts, the torrents of water arising may in a short time tear down and distribute as sediment to distant valleys the material accumulated by the slow movement of centuries. Indeed, it has been questioned by some, whether the larger part of the grist of the glacier has not been thus transported far beyond the extreme limits reached by the ice itself. This transportation by water from the front of glaciers is certainly of immense extent. Every subglacial stream is surcharged and milky-white with sediment as it emerges from the ice-front' (p. 121).

Although such considerations as these may require the theory (as stated by Professor Lewis in his paper), namely, *that every glacier must have its moraine*, to be made less general,[1] it yet remains sufficiently true to justify the great lines along which he carried on his investigations.[2]

While in some districts there may be no accumulations near the glacial border worthy of being called terminal moraines; in other districts those accumulations may be so marked as abundantly to merit the name.

The question simply concerns the geographical definition of the course of some particular glaciers, and neither traverses the fact that terminal moraines exist among glacial deposits, nor challenges the position that wherever they occur they may be taken as measures of the size of the glaciers by which they were produced.

In justice to Professor Lewis it must be noted that he did not claim to have *precisely* determined the boundaries of the great terminal moraines of the glaciers of Great Britain and Ireland.

In conversation he constantly admitted that he might prove to be mistaken in drawing their lines through this locality or that; and, indeed, he frequently made corrections in his own map as his survey of the country continued to be carried on. What he earnestly contended for was the actual occurrence not merely of local but of true *terminal* moraines; and what he evidently desired and spared no labour to promote was an exhaustive inquiry into their positions, character, and limits.

---

[1] Mrs. Lewis informs me that Professor Lewis admitted that the district examined by Dr. Wright between the Appalachian Mountains and the Mississippi might possibly be an exception to the general rule, as showing no distinct ridge of moraine.— H. W. C.

[2] Professor E. W. Claypole, in an article in the *Popular Science Monthly*, April 1893, p. 776, remarks that 'in Ohio at least, chiefly by the labours of Mr. Leverett, moraine after moraine has been added *outside the one at first thought to be terminal*, until the true terminal moraine now *almost coincides* with the southern margin of the drift.'— J. F. L.

V

Have there been successive elevations and depressions of the land during the glacial epoch? or has there been one, and only one, great submergence? or has there been merely one slight submergence of comparatively little geological importance? or has there been no submergence at all? These are questions of vital importance, and were studied by Professor Lewis with characteristic originality and courage.

When I first had the privilege of meeting him he was almost more than doubtful whether there had been in England any depression of the land at all.

He appeared to think that *all* the phenomena may be accounted for by one great advance of the ice over an England standing at its present level, followed by a retreat. One re-advance of the ice, however, but only one, Professor Lewis admitted might possibly have taken place.

In his chief papers, however, he states his opinion that a submergence of about 100 feet on the East coast and 150 feet on the West coast of England took place, although he had evidently some difficulty in admitting even that small amount of depression; since he regarded as 'moraines' deposits which in both Wales, Scotland, and Ireland especially, come down nearly to the sea-level, and show (as he contends) 'from their sharp and distinctive outlines that they have never been submerged.'

Moreover, many of the beds, although not all, within the 100 to 150 feet level, which contain marine shells, Professor Lewis attributed to the action of a great glacier, which filled up the sea—as, for example, the Irish Channel—and, travelling onwards, tore up the sea bottom in its passage, and distributed the material so derived over the land.

A remarkable proof that Professor Lewis was right in this account of the origin of at least *some* of the shell-bearing boulder clays found at low levels has been given by the excavations recently made for the purpose of constructing the Ship Canal between Manchester and Liverpool.

A series of boulder clays and sands has been brought to light, in which the boulder clay resting immediately on the basement rock contains both (1) material derived from the rock beneath it; (2) material from a sea bottom; and (3) material brought from distant mountains. Fragments of local rock have been torn off and imbedded in the boulder clay resting upon it. The basement boulder clay, as well as the superimposed boulder clays and sands, contains marine shells in a more or less broken and fragmentary condition. Erratics, some of which are unquestionably derived from Cumberland and Scotland, occur both in the lowest bed and here and there throughout the deposits, and are associated with blocks of *glaciated* local rocks. At the same time there are extraordinarily clear proofs that the ice (to which alone it is possible to assign the formation of these boulder clays) was in *motion*, and pressed onwards from the north-west towards the south-east. Under the guidance of a capable geologist, Mr. Percy F. Kendall, F.G.S., I have examined the Ship Canal sections, and can come to no other conclusion than that the boulder clays, and at least a part of the sands, are the results of the *movement* of a great glacier which came down from the north-west into the Irish Sea, carried the débris it there accumulated over the plains of Lancashire and Cheshire, and mixed it with locally derived material.

Whether *all* the district was a land surface when the glacier came down upon it, and whether some of the sands may not have been accumulated during a submergence, are questions open for discussion; but that *a glacier has certainly acted upon the surface of the local rock* appears to me proved. The boundaries and the depth of this glacier, not its existence, are, I think, the questions left for determination.

The Manchester and Liverpool Ship Canal sections so strikingly illustrate some of Professor Lewis' arguments that a more detailed account of them—kindly drawn up by Mr. Kendall—will be given in a subsequent part of this volume.

The many questions which are involved in the various theories concerning the elevation and depression of the land cannot *all*, however, be solved by the fact that fossiliferous boulder clays and sands can be and have been formed by glaciers advancing from the sea.

So far as this one fact, taken by itself, is concerned, land-ice might have existed in Lancashire and Cheshire at one period during the glacial epoch, and yet submergence might have taken place either before or after that period. I do not say that this was the case—my duty is not to argue the point, but to represent Professor Lewis' opinions —I simply point out that further evidence must be sought for, as his own papers fully show, and that the inquiry requires the extension he himself had resolved to give it in other and wider directions.

The glacial deposits—or rather it would be better to say, in order to avoid making any assumption as to their origin even by implication, the beds—belonging to the glacial epoch which occur up to the height of 400 to 450 feet, and are frequently fossiliferous, have next to be considered. These are commonly supposed to be marine and to prove submergence; but Professor Lewis believed them to have been formed within great extra-morainic lakes established in connection with the ice-dams set up by glaciers, in some cases pressing over the land from the sea, in others descending from mountain regions, sometimes against and sometimes in the direction of the drainage.

In a passage in one of his papers, indeed, he says: 'I hold that no satisfactory proof is to be found in Great Britain of any submergence during the glacial epoch of more than 400 feet.' But, as his researches extended, he reduced 400 feet to 150 feet at the utmost, and credited extra-morainic lakes exclusively with the production of the 400 to 450 feet deposits.

As his observations gained a yet wider range, however, he was disposed to think that some few of these clays had a different origin. The California and Frankley Hill boulder clays—presently to be described—at the 500 feet and 900 feet levels, for instance, he referred to the original advance of the ice-sheet at the time of its greatest extension, and he intended to search the country to see whether he could not find elsewhere clays of a similar character. *This ice-sheet, however, he relegated to a first glacial epoch.*

But the *fossiliferous* 400 to 450 feet deposits, without exception, he always explained by the supposition that a landward advancing glacier pushed up from the sea bottom over which it travelled shell-bearing clays and sands, formed an ice-dam, and thus helped to establish a lake in which these marine clays and sands would be included, and, together with the erratics closely associated with them, would be subjected to the action of its own waters and of the torrents which ultimately broke forth from them.

According to his contention, for example, were the great North Sea glacier only 300 feet thick (a very moderate estimate), and were England at the time depressed only 100 feet lower than it is now, a glacial dam would be formed at the mouth of the River Humber, and the result would be the creation of an inland fresh-water lake which would reach what is now the 400 feet contour line.

Several of these extra-morainic lakes of Professor Lewis' are described in his papers; and in conversation he was accustomed to appeal to them even more vigorously than in his writings, to account for the presence, especially at any levels between 100 to 150 feet and 400 to 450 feet, of the deposits which on the strength of the fossils contained in them have been usually pronounced to be marine.

I only knew him once shaken in this conviction, and that was when he accompanied me to Lilleshall, Ketley, and the district around Wellington, in the midlands of England.

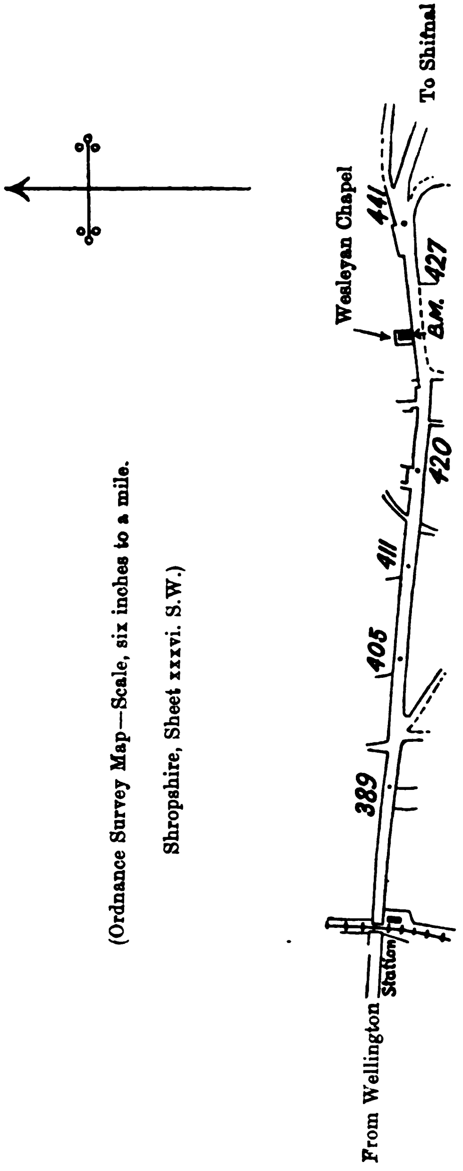
At Lilleshall, 463 feet above the sea, such Arctic shells as *Natica affinis*, *Astarte borealis* occur; and in the manuscript notes made at the time, Professor Lewis writes, 'Genuine marine clay at Lilleshall, but not at Moel Tryfaen.'

At Ketley, *about* 400 *feet* above the sea,[1] shells such as *Turritella communis*, and others not specially Arctic, abound, and somewhat elaborate sections are exposed.

Of the *sand* at the bottom of the section he writes (also

---

[1] The subjoined sketch will show the exact heights of the ridge along which the deposits occur, Fig. 1.



(Ordnance Survey Map—Scale, six inches to a mile.

Shropshire, Sheet xxxvi. S.W.)

FIG. 1.—Ketley.

in manuscript notes taken on the spot): 'On the north side we see at the bottom a shell-bearing sand *clearly marine*, and full of fragments of shells, and occasional whole ones, being a red sand without marked false bedding;' and of the *clay*: 'I cannot say that this clay was made under a glacier. It lies quietly on the older sands as if made by the same body of water.'

As we stood together on one of the series of ridges of fossiliferous sands and gravels, which sweep round in a wide curve for several miles, and have evidently been rounded off and divided by flowing water, Professor Lewis exclaimed, '*This is marine!*'

These sections are so important, that I subjoin Professor Lewis' own notes:—

'I examined some brick-yards and sand-pits near Wellington, and on the north-west side of the Wrekin.

'In a brick-pit I saw an exposure of 5 feet of brick clay, containing many angular fragments of local rock with pebbles and erratics from the Lake District, Scotland, and Wales.

'I made a collection of boulders found here; which include Wrekin red granulite, or granitoidite, or binary granite (see analysis of this rock by Player in *Proc. Brit. Assoc.*, Birmingham, 1886, who calls it Ercal Hill granulite), flints, striated Silurian shale pebbles, Lake District felsites and granites, &c.

'In another pit I saw a red sand resembling that of Lilleshall, but here devoid of shells.

'There seems to be no genuine moraine heaped against the Wrekin, as I at first thought.

'With Dr. Callaway I visited some sand-pits in Watbury Street, one mile east of Wellington.

'The drift forms a continuous ridge from Wellington.

There are two pits both freshly exposed, one on the north, the other on the south side of the road.

'On the north side we saw at the bottom a shell-bearing sand clearly marine, full of fragments of shells, often quite sharp and thin, and occasional whole ones; being a red sand without marked false bedding.

'On this is sand 10 feet thick, and more free from shells.

'Over this is a tough loamy clay, stratified, perhaps the india-rubber clay of California, being free from shells.

'Erratics appear at the top of this clay, which is a genuine boulder clay in which Criffel granites and other erratics, often well striated, occur, forming the top of the section.

'Across the road is quite a different succession, the pit being at a somewhat higher level. No shell-bearing sand occurs here, but we have some 30 feet of red sand alternating with bands of clay. Clay is seen at the bottom of the pit, then sand, and then occasional layers of sandy clay in the sand.

'The upper part of the sand, which is not false-bedded, but is horizontally laminated, shows a succession of ripple-marked horizontal layers which project by weathering.

'These ripple marks have been described by T. M. Reade[1] and by Mark Stirrup.[2]

'On top of the whole is a clay full of erratics; a true boulder clay or till, 5 feet deep, of gray colour, being a brick clay such as that I examined on the other side of Wellington, near the Wrekin; and the same as that on top of the section on the north side of the road.

'I cannot say that this clay was made under a glacier. It lies quietly on the older sands, *as if made in the same body of water.*

'In the pit on the north side at one end the clay and the sand are curiously intermixed and drawn out into tongues and bent over.

---

[1] *Quart. Journ. Geol. Soc.*, 1884, p. 207. [2] *Proc. Man. Geol. Soc.*

'This is not due to a glacier but to *creep* down the side of a hill, as can readily be proved here.

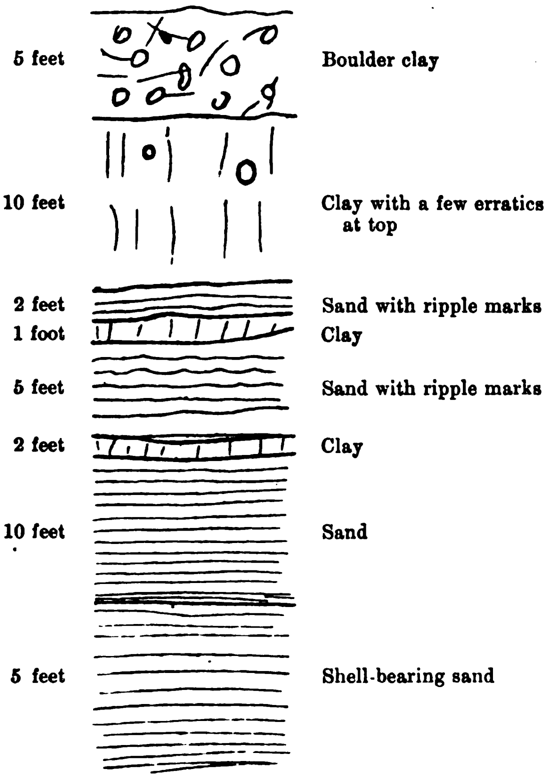


FIG. 2.—Section of Ketley Sand-pit, Watbury Street, one mile east of Wellington.

'The great interest in these two sections (which are combined and generalised in the above section) lies in the fact that there *are no unconformities, but passages of each deposit into the next, indicating a continuous submergence under varying conditions.*

'We first have a temperate sea[1] containing mollusca; then life disappears as the ground rises; then some clays appear with occasional gravel, as if the water was cold and charged with mud, and was, perhaps, still getting shallower; then a few dropped boulders are seen in the mud, as if brought by icebergs; and, finally, a mud, full of boulders and scratched stones from the north, indicates a body of water full of floating ice, and perhaps frozen over, the water now being probably fresh or practically so.

'Though the drift ridge is shaped somewhat like a moraine (but without meres), the inner structure is so different that I cannot regard it as such.

'On going northward from Wellington to Crewe, one sees a similar ridge of sand-hills about Adderley; and meres occur in this region. Is this the terminal moraine near Adderley?'

Professor Lewis did not, I think, retain the first impressions made upon him by the Wellington district sections.

Indeed, the last time I met him he fell back upon his theory of an extra-morainic lake, partly formed by a barrier of ice advancing from the sea, and charged with shell-bearing mud, and accompanied by a depression not exceeding 150 feet, as sufficiently accounting for all the 400 to 450 feet fossiliferous deposits, including those just described.

The high-level shell beds, such as those which are found on the Three Rock Mountain in Ireland at an elevation of 1,200 feet, and on Moel Tryfaen in Wales, where they stand at 1,370 feet level, Professor Lewis explains by the hypothesis that they were carried by the thrust of a glacier to their present positions.

---

[1] The Lilleshall beds, however, it must be remembered, contain some Arctic species of mollusca. The indications are that in this district there are remains of two faunas - an Arctic or sub-Arctic, and a temperate one also.

He holds as a broad principle that, wherever in Great Britain marine shells occur in glacial deposits at high levels, it can be proved both by striæ and the transport of erratics that the ice advanced on to the land from out of the sea.

The facts on which he bases, and the arguments by which he sustains, this principle are stated with such fulness and force in his papers and notes, that no explanatory remarks are needed.

Whether Professor Lewis' bold hypothesis survives the criticisms through which it will have 'to run the gauntlet' or not, it is one which must be examined with a care equal to that which he has bestowed upon its establishment. In science, as in other branches of human knowledge, the frank and able statement of a heresy is a frequent prelude to the discovery of the truth.

The distribution of erratic blocks, both at high and low levels, is intimately connected with the problems relating to submergence. Were they brought into their existing positions either by land-ice or icebergs, or were *both* those agencies at work either at different localities during the same period, or at the same localities during successive periods?

If the erratics were brought by icebergs, did they float over a sea which covered the present land, or over morainic lakes? If they floated over morainic lakes, what depths must these lakes have had to enable their bergs to carry erratics to the very considerable heights upon which they have rested; and does the physical geography of the country render possible the supposition that lakes of the depths required could be formed?

Professor Lewis frequently refers both directly and indirectly to these questions. He does not admit that the high-level erratics afford any proof that an iceberg-laden sea ever covered the eminences on which they stand; neither does he admit that any erratics at low levels show the prevalencé of marine conditions, save and except indeed the few that might have been floated off during a very slight depression of the ice-clad land.

It may assist in the examination of the theories under discussion, if I add a brief *résumé* of the leading facts concerning erratic blocks which have to be explained.

As the Secretary of the Erratic Block Committee of the British Association, I have given in its Report for 1890 the following account of the chief results which may be regarded as established—at least, so far as its inquiries have been carried on—in one great district, namely, the Midlands of England, where boulders are found in great profusion and at many levels.[1]

Professor Lewis himself travelled over this district, and was of opinion that his theories offered the only possible explanation of the phenomena.

1. The erratics have been deposited at distinct periods. At least two of these periods can be well ascertained. In some cases the collections of erratics which have been supposed to show the intercrossing of their streams are really the remains of distinct periods of action. Not that there has been no intercrossing, but that all the supposed cases of it are not accurately described by that term.

2. There are deposits of erratics in the Midland area which are entirely distinct from each other, erratics from special districts being grouped together.

---

[1] *Report of the British Association for the Advancement of Science,*

3. Groups of boulders occur in which those from different and distant sources are to some extent intermixed, and this intermixture of streams of erratics has to be studied in connection with any changes in the physical geography of the country that took place during the glacial epoch itself.

4. Local hills have formed no effective barrier to the distribution of some portion of the erratics. In the Midlands, e.g., erratics are abundant at a level of 648 feet, and not unfrequently lie on the edges of the precipitous side of a hill.

5. Some streams of erratics, however, have travelled under conditions imposed by the hills and valleys as they now exist.

6. Glaciated boulders of local origin are intermixed with erratics from a distance, but it would seem that where the northern erratics are numerous very few local boulders are intermixed.

7. A distinct distribution of boulders from local hills has taken place.

8. Erratics have been deposited at almost every level, and it may be added that beds roughly composed of erratics of all sizes are sometimes separated from each other in section by clays and sands, occasional boulders being found in the separating clays.

9. A very considerable proportion of the largest erratics are either upon the surface or just beneath the surface; how far clays and sands may have been washed away from them cannot be known.

10. The erratics differ notably in shape. Many are angular and subangular, many have their edges much rounded off, others are rough and broken as though just torn from the parent rock. In some accumulations of erratics there are signs of considerable rolling and wearing

as by water, in others the ice-markings are quite fresh and unworn.[1]

VI

It will be remembered that in the 'Notes' by Mrs. Lewis included in this Introduction it is remarked that Professor Lewis, at the commencement of his glacial studies, believed in the existence of *two* glacial epochs, separated from each other by a long interval of time, and that he afterwards changed this view and accepted the theory that there has been only one.

At the time when he prepared and read his English papers, he still held the opinion that there has been *only one glacial epoch.* In a postscript, however, to his paper on *Some Important Extra-Morainic Lakes*, added to the abstract published in the *Geological Magazine* (November 1887, p. 516), and which will be found printed in this volume, he states that since the paper was read he had seen traces of the existence of a much older series of glaciers than he had described, and that he desired 'the glaciers and their bordering lakes' of which he had given a detailed account to be '*considered as belonging to the last glacial epoch,*' thus returning to his first opinion, at any rate so far as England is involved.

Mrs. Lewis has already mentioned the fact that this modification of opinion was due to an examination of Frankley Hill, and of various sections and erratics in the neighbourhood of Birmingham.

The subject, however, is of such importance to the full understanding of Professor Lewis' papers, as well as of such general interest, that I think it will be well to arrange together here the extracts from his hitherto unpublished Field Note-Books which refer to it, and to add a few explanatory remarks.

---

[1] See a paper on 'The Boulders of the Midland District,' by Fred W. Martin, F.G.S., in the *Proceedings of the Birmingham Philosophical Society*, vol. ii. Part I. p. 85.

Frankley Lower Hill is a small eminence about eight miles to the south-west of Birmingham, which rises to the height of 793 feet above the sea. (See Map X. p. 293.)

In a cutting of the railway passing through the hill, the following section was exposed, but was covered up at the time of Professor Lewis' visit:—

Permian clay.
Sand of clay texture.
Yellowish sand.
Grayish sandy clay, with Bünter pebbles.
Clay, somewhat sandy.

The permian sandstone was exposed at one point in the section, and fragments of it were scattered through the sands and clays.

I found erratics in the sands and clays of the cutting itself, although they were rare; but on the summit is a group of boulders which Professor Lewis saw. Although some of them had been destroyed or removed, several large ones were remaining at the time of his visit. On a previous occasion I had counted twenty felsites, two basalts, and one mass of vein-quartz. Several of the felsites were of considerable size, one nearly at the summit of the hill measuring 4-5 feet × 3 feet × 2 feet; another 4 feet × 4 feet × 2 feet.

These remarkable high-level erratics I had catalogued as of Welsh origin, being fortified in that opinion by

Professor T. G. Bonney, who examined the specimens and wrote: 'I feel certain they are from Wales, and are of lower silurian age, but whether from the interbedded volcanic rocks of the [Lower] Llandeilo or the Bala series I am not sure. One would expect them to come from the Arenig district. I have seen nothing like them in the Lake District.'

On the opposite hill—Romsley Hill—separated from the Frankley Hill by a narrow valley, three other boulders occur at an elevation of 897 feet. These are also felsites of the same type as those on Frankley Hill, and these Professor Lewis also saw.[1]

In the paper on *Extra-Morainic Lakes*, read before the British Association at Manchester, September 2, 1887 (which is printed in this volume), Professor Lewis suggested that the '*supposed Welsh erratics*,' on Frankley Hill, are '*in place and due to an outcrop of the palæozoic floor*.'

On his first visit to the locality, indeed, he predicted that 'a core of pre-Cambrian felsites and other old rocks' would be found, from which the blocks on the surface and in the section were derived.

On the occasion of his second visit, on which I accompanied him, as well as on the first, we took with us two strong 'navvies' and attacked the hill itself.

Should a boss of palæozoic rock exist it would necessarily be found near the summit of the hill; unless it occupied this position, the blocks '*supposed to be erratics*' could not have been broken off from it, and reached the level at which they now remain. An excavation was therefore made on the slope of the hill on which Frankley Lower Farm stands, *above* the beds exposed in the railway cutting and also a little *above* the highest of the large blocks of felsite resting on the surface. The result was the discovery of a compact boulder-clay of unquestionably glacial origin. A loose mass of débris was at first passed through, but the clay became more and more compact as the excavation increased in depth, until at 10 feet beneath the surface the compact boulder clay appeared, the upper débris being evidently a wash of the boulder clay beneath it. This boulder clay contained in great abundance felsites of several Welsh types, slates of Welsh type, fragments of coal, and permian blocks. Among these rocks felsites largely predominated.

---

[1] The highest of the Frankley Hill and Romsley Hill boulders were determined by Mr. W. Mathews, who originally drew attention to them.

Several specimens of hard felsites and a small block of coal were well-smoothed and finely striated—the polish and the striæ being quite fresh and unworn. A large proportion of the blocks were distinctively angular, and even the pebbles as a general rule were irregular in shape, and showed no signs of having been rolled by running water.

A similar excavation was made near the summit of Romsley Hill, 897 feet above the sea, and showed indisputably that the large felsite erratics on the surface directly rest upon the permian breccia.

I have written thus far from notes which I made in the field when in company with Professor Lewis, and which received his general approval.

I subjoin some passages I find in his own Note-Books referring to these visits to Frankley Hill which I have just described.

'At Rubery I leave the train and go to the top of Frankley Hill, and on the ridge in Frankley Farm I get two men to sink a well 10 feet deep. In the field are many fragments of silurian shale, sometimes fossiliferous, also vein-quartz, and angular fragments of Arenig felsite. Huge blocks of this felsite lie at the side and base of the hill, near the railway. None of these are glaciated, and not one is rounded.

'The pit on Frankley Hill being sunk from 10 to 11 feet, and water coming in, I stop work. We have passed through a genuine till. I made a full collection of specimens, nearly all of which were angular, and many of them were well glaciated and scratched. I took some finely glaciated stones out myself. Silurian shale (sometimes with trilobites) is commonest; a finely glaciated piece of coal, 6 inches long, was found. At 6 feet deep is a boulder of Arenig felsite 1½ foot × 1½ foot × 1 foot, angular, but smoothed on one side. This is a highly interesting deposit. It is the till of an ancient glacier clearly full of angular fragments. *Is it not the glacier of the first glacial epoch?*'

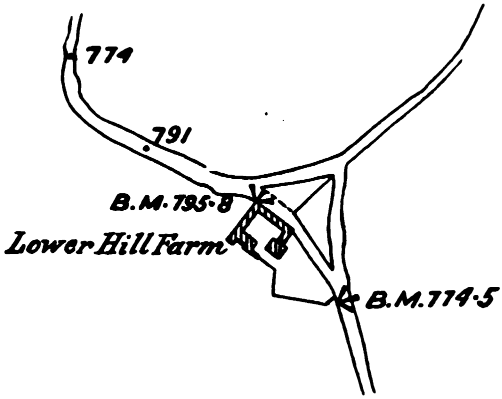


FIG. 3.—Frankley Hill. (Sheet x., S.W.)

At Romsley Hill the boulder clay was absent. Although the extraordinary character of the breccia of this hill—composed as it is of angular fragments—gives it, at first sight, an *appearance* of being glacial, Professor Lewis, so soon as it was examined, had not the slightest hesitation in recognizing the fact that, whatever its origin, it is permian and not till of the glacial epoch.

He writes: 'I go to the top of Romsley Hill. On the very summit is a well 100 feet deep, going through permian breccia. A digging at its top gives an exposure of this remarkable breccia. It is made mainly of angular fragments of volcanic rocks of various kinds, felsites, ashes, &c. It is called locally "Rotch" or "Roch." This is the celebrated permian conglomerate held to be of *glacial origin* by Sir Andrew Ramsay.

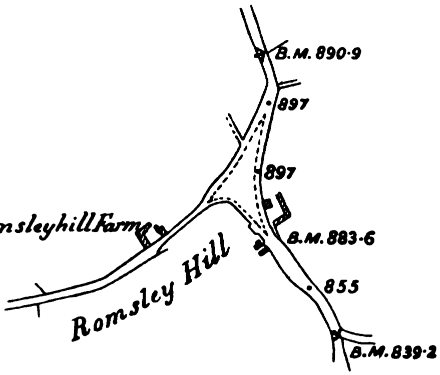


FIG. 4.—Romsley Hill.

'I had a hole dug 10 feet deep in the "Rotch." Many angular fragments were taken out, of felsites, porphyries, tuffs, &c. I found no Arenig boulders. This is permian breccia. On top of the hill are four large boulders, three of Arenig felsite, and one said to have been taken out of the "Rotch" slightly beneath the surface.

'*These boulders came from Wales in the first glacial epoch, since which time great erosion has occurred.*'

The peculiar striation and character of these boulder clays and erratics indeed rendered it inevitable that Professor Lewis, holding the general views he did, should come to the conclusion that they must be referred to a different epoch from that to which the extra-morainic lakes and great terminal moraines which he had described belonged.

The configuration of the country, and the levels of its plains and undulations of ground, entirely exclude the theory that any extra-morainic lake could have been formed of sufficient depth to have floated boulder-laden bergs, and even carried masses of true glacial 'till' to the summits of the Frankley and Romsley Hills. Such a lake would require to have been more than 900 feet deep; and no boundaries capable of confining such a mass of water either now exist, or can be imagined to have existed during the glacial period. These hills also stand twenty miles to the south-east of Professor Lewis' great terminal moraine; and no glacier so vast as to sweep over them could have had its course marked by those particular deposits to which Professor Lewis gives that name; or would be confined within an area in the slightest degree corresponding with the glaciated region indicated by them. I do not doubt that Professor Lewis would have more than questioned whether the high-level glacial deposits under discussion prove *submergence*. Indeed, I gathered from him in conversation that he attributed them, together with any corresponding deposits that further investigation might show should be classed with them, to the upward push of a great glacier of the first epoch. The distinction between the two epochs, however, is the point now being considered.

Another series of sections, although at a lower level, had a strong influence in bringing Professor Lewis back to a belief in two epochs.[1]

I accompanied him to some clay pits at 'California,' a village about four miles south-west of Birmingham, and in the direction of Frankley Hill, and what he saw there confirmed him in the opinion that in England he had been chiefly working among the remains of their existence left by the glaciers, morainic lakes, rivers, and torrents of the later glacial period.

The height of the California clay beds is about 520 feet above sea-level; and at their base, resting on the Bünter sandstone, is a true till containing Welsh erratics, intermixed with glaciated blocks of local origin.

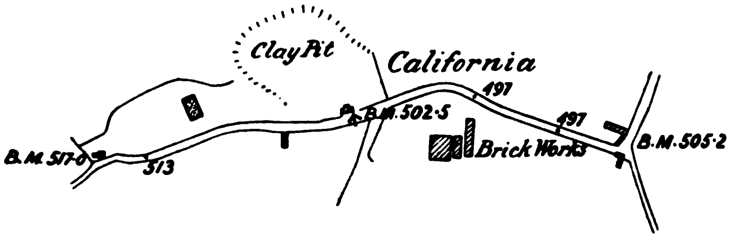


FIG. 5.—California.

Here again, as we studied the general aspect of the country, Professor Lewis said that no lake could have stood at the level of the sections.

He also pronounced the California till to be identical with that on Frankley Hill.

In his manuscript notes he writes as follows:—

'California (October 28, 1887).—Admirable and fresh section. Here and now for the first time[2] I see the *lower*

---

[1] That is for Great Britain. Professor Lewis held that the phenomena of the last ice period in Great Britain correspond in time and general characteristics with those of the great glacial epoch in North America.—J. F. L.

[2] This alludes to his previous visits when the full section had not been perfectly exposed.

till, full of angular pieces of sandstone, shale, permian rock, and occasionally Arenig felsites. They are rarely striated; none are rounded; and all are unusually angular as in a breccia. It is identical with that I saw on Frankley Hill: red colour, compact, *unlike recent glacial till*; like old Scotch till, according to Dr. Crosskey.

'On this is a sand of yellow colour; made mainly of quartz with shales, silurians, &c.

'In the second pit this sand is seen plainly overlaid by a quite thick deposit of india-rubber-like clay, almost free from pebbles and fully 25 feet thick. In the upper part of this clay an erratic occasionally occurs.[1]

'The clay is laminated very indistinctly.

'On this is the wash of quartzose gravel, and brick clays with boulders, being probably the same as the flinty gravel of the Midlands and the "northern drift" of South England.

'There is a fine exposure in the third pit.

'*The lower till is, if not made by a glacier, made by water close to the end of a glacier, perhaps when it was at Frankley Hill.*'

Before he had seen the lower till Professor Lewis wrote of the beds 2, 3, and 4: 'There seems to me but one clay and gravel, both of the same age and due to fresh-water torrents issuing from the melting ice;' and respecting the gravel of the bed 1, he especially remarks 'this is clearly a torrential gravel resembling the Philadelphia red gravel.'

---

[1] In his manuscript Professor Lewis adds *dropped from an iceberg*; but I think these words were merely the record of a suggestion I made, since they are plainly inconsistent with his clearly expressed conviction that there were no signs either of submergence beneath the sea or of a deep lake. The erratics are not confined to the upper part of the clay, although those seen by Professor Lewis were in the upper part. The whole mass of clay is (as he notes) singularly free from stones. The erratics are only here and there imbedded in its mass.

1	4 feet	Surface brick clay and yellow gravel.
2	25 feet	Occasional stones in upper part of clay; permian blocks being striated. Some Welsh erratics. Tough red (india-rubber) clay. In lower part generally free from stones; tenacious.
3	15 feet	Yellow false bedded sand, often fine. Quartzose sand.
4	6 feet	Tough till with striated Welsh rocks, felsites and shales, &c.
		Bünter sandstone.[1]

---

[1] This section is not found in its completeness at any one point, but is drawn from three adjacent clay pits. In one 4 and 3 occur; in another, 1, 2, and 3; in another 1 and 2. I have no doubt, however, of its correctness. The section I have copied from Professor Lewis' Note-Book is precisely the same as the section I made out and published many years ago.

In a manuscript note on 'the origin of the so-called glacial drift about Birmingham,' Professor Lewis indeed maintains with regard to this 'drift' generally, that it is 'the product of large rivers which at the time of the melting of the great glacier[1] flowed across the country. The glacier extended no farther south than Madeley, some thirty miles north of Birmingham, and its terminal moraine is finely shown in the cuttings of the London and North-Western Railway. Great rivers issued from the ice at that point and ran southward, and one of them passed Birmingham. . . . The contorted gravel sections described by Mr. Martin are due to torrents and a frozen soil.'[2]

VII

It may prove of service to the reader to add one or two notes upon the senses in which Professor Lewis employs the terms commonly current in glacial geology.

His papers, and especially his Field Notes, having been written *currente calamo*, suffer from the lack of his personal revision somewhat markedly in the way in which the terms used have sometimes a broad and general, and at other times a restricted and technical sense.

In the majority of cases, whenever a doubt arises as to the precise place in the glacial series to which Professor Lewis refers the deposit he is describing, the context will make it sufficiently clear.

Any difficulties that may remain after due consideration has been given to the context, will perhaps be removed if attention be paid to the following brief summary of the meanings given to a few of the words and phrases which are of the commonest occurrence and of the greatest importance :—

---

[1] Doubtless the reference is to Professor Lewis' great glacier of the second epoch ; the *lower till* was the only deposit in the district he assigned to the first epoch.

[2] See a paper on 'Some sections of the Drift between Soho and Perry Barr, near Birmingham,' by Fred W. Martin, F.G.S., *Proc. of the Birmingham Phil. Soc.* vol. v. p. 364.

Till.—This term is sometimes employed as interchangeable with 'boulder clay,' but only when by 'boulder clay' is meant simply a clay formed during the glacial epoch, and the precise period of its origin is left undefined. It is generally restricted to the unstratified stony mass, containing a large proportion of glaciated stones, made by the direct action of a glacier during the oldest and farthest extension of the ice. The ideas of age and the movements of land-ice are, as a rule, both involved.

Boulder Clay.—In one paper especially the term 'boulder clay' is confined to the clayey portion of the deposits which Professor Lewis regards as 'extra-morainic,' and which consist of the mud which was accumulated at the bottom of a lake, and into which erratics were dropped by lake icebergs. But this term is also used to denote (1) a clay containing erratics, whether formed within or without a 'terminal moraine'; or (2) even a glacial clay which may be either a 'till' or what is called 'a ground moraine,' in the most narrow and restricted sense.

Moraine.—This term is employed in a wide general way to denote *all* the deposits accumulated by a glacier in the course of its movements, and the descriptive words 'lateral,' 'medial,' 'terminal,' are applied to moraines in the usual way; but (1) those deposits which mark the extreme boundaries of a great glacier are called emphatically '*the moraine*.' 'The moraine' as thus defined is also referred to as '*the moraine proper*'; (2) moraines are also spoken of as being within 'the moraine,' or 'the moraine proper';

and in this case they are only regarded as indications of the presence of land-ice, at different stages it may be of its retreat, or it may be of its advance.[1]

Morainic Material.—By this phrase the material originally derived from moraines, but subsequently subjected to aqueous action, is generally denoted. Occasionally, however, it is applied to any fragmentary portion of a moraine whether or not redistributed by water.

Ground Moraine.—This name is given to some deposits which Professor Lewis regards as having been made *under a glacier*—i.e. which are not the deposits which register the furthest point of its extension, but those by which the course of its own passage has been marked. According to Professor Lewis, a 'ground moraine' has characteristics of its own. It is neither lateral, terminal, nor medial, but is composed of the material collected by the glacier itself in the very bed over which it travels. There may be a moraine, which is not a 'ground moraine,' within 'the terminal moraine,' or 'the moraine' or the 'moraine proper' (as Professor Lewis indifferently calls the boundary moraine of a great glacier), fragments of the succession of moraines formed by the advancing or retreating ice having possibly been preserved. A 'ground moraine,' however, is something more than a moraine within a terminal moraine: it is a deposit composed of fragments torn by the glacier from the basement rock over which it passes, intermixed with the clay, sand, and stones which it bears along with it. I am not now arguing the question as to whether a ground moraine of this character could be formed beneath a glacier, or, if it could, whether it would not occur where the glacier came down to the sea as in Greenland, and denote its entrance into the water rather than its passage over the land; I am simply attempting to define the term as it is used by Professor Lewis.

---

[1] The moraines lying within the 'terminal moraine,' which mark the various points where the solid ice-front halted for a time in its retreat toward its source, are called *moraines of recession.*— J. F. L.

I have had the opportunity of examining a deposit which Professor Lewis regarded as a ground moraine. Mr. Kendall conducted me to a section at Portwood, Stockport, which he had also shown to Professor Lewis. Resting upon the permian rock, which appears to have been violently broken up, is a bed containing numerous permian blocks with small stones and pebbles, standing on end, together with an occasional erratic from the north of England, in a matrix of sandy clay. Mr. Kendall informed me that Professor Lewis said, 'Here, for the first time in England, I see a true ground moraine.' This Portwood bed is capped by a series of clays, sands, and gravels.

Judging from this expression of opinion, I cannot doubt that Professor Lewis would have pronounced the lowest bed of the glacial series in the Ship Canal sections,[1] which exactly corresponds with that occurring at Portwood, to be also a ground moraine.

Closely connected with the definition of terms are the methods by which Professor Lewis distinguishes between the various deposits to which these various terms are applied.

Here again the fragmentary character of the records left of his work causes difficulties to arise. Had he lived to complete his labours he would unquestionably have described more precisely both the criteria he used in recognising a moraine, and the way in which he discriminated between those boulder clays *within* a moraine which he attributed to land-ice from those boulder clays *outside* a moraine which he believed to be lacustrine in their origin. Notwithstanding, however, the partial information we have upon these and similar points, the specific determinations given by Professor Lewis are sufficiently clear to afford valuable aid to the inquiries of others, while he has most usefully emphasised the necessity of distinguishing between the members of a vast series of beds which are not unfrequently roughly classed together without adequately detailed observations respecting their distinctive peculiarities of composition and position.

---

[1] Vide Appendix for a full description by Mr. Kendall.

Knowing that Professor Lewis was largely directed by his American experiences in all his subsequent researches, I wrote to Mr. Warren Upham, of the United States Geological Survey, in order that I might obtain a better understanding of the methods pursued by American geologists for the determination of one important series of beds to which Professor Lewis drew especial attention in England. The reply with which Mr. Upham kindly favoured me throws so much light upon some of the tests which Professor Lewis evidently applied to the glacial phenomena of Great Britain, that I cannot refrain from subjoining it for the benefit of English geologists:—

'In reply to your inquiry as to the means of discriminating glacial lakes and extra-morainic lakes from ordinary glaciated areas which include more or less of gravel, sand, and clay deposited by broad river floods during the melting of the ice-sheets, or from somewhat similar beds that were laid down in the sea during marine submergence, I must confess that in many districts much doubt and difficulty would attend the best attempts towards such discrimination. In the case of Lake Agassiz and the enlarged glacial representatives of our great lakes tributary to the

St. Lawrence, we have well-defined *marginal beaches* and *channels of outflow* from those levels crossing the present main watersheds of the continent. These *outlets* are also discernible for many of our smaller glacial lakes—that is, lakes formed by the barrier of the ice-sheet across the lower portion of a river basin; and they demonstrate that these basins were filled with lakes, for no bay or gulf of the sea could have such channel of overflow. *They are the crucial test of glacial lakes.*

'The larger glacial lakes also have admirably developed *terraces of erosion, beach ridges* (including spits, hooks, and bars) of shore gravel, shingle, and sand, and great *delta deposits.* The smaller glacial and extra-morainic lakes, though often clearly shown, by the contour of the country and the relationship of the glacial moraines, to have certainly existed for some time, yet had too small an extent of lake surface to permit the formation of such powerful waves as to form either noteworthy cliffs (i.e. cut terraces) or beach ridges of gravel and sand; but *such small lakes are often demonstrated by well-marked deltas brought into* them by *tributaries.* A large share of the deltas of Lake Agassiz were supplied from englacial drift, which had been contained within the ice-sheet, and was brought by rivers formed on the melting ice-surface.[1]

Our Mississippi and Missouri loess, which many would attribute chiefly to lacustrine deposition, *seems to me rather to be the sediment of broad river floods,* fed largely from the glacial melting and prevailing during the departure of the ice-sheet, covering the flood-plains only during the warm portion of the year. Through a large part of the year these areas were dry alluvial land, affording place for the air-breathing land shells which are plentiful in many portions of our extensive loess beds.'

---

[1] Vide *Report of Exploration of the Glacial Lake Agassiz in Manitoba,* by Warren Upham, Montreal, 1890, pp. 54, 81, and 89 E.

In Great Britain, Professor Lewis had of course to deal only with such evidence as there may be for the existence of comparatively small glacial lakes, and the kind of evidence he believed he had discovered is well indicated in Mr. Upham's letter.

In bringing my task to a conclusion, I have on Professor Lewis' behalf to thank the very many friends who gave him—as throughout all his Note-Books he is constantly acknowledging—their highly valued and most willing assistance.

I find the following passage added to the manuscript of one of his papers :—

'Personally I take pleasure in expressing my sincere obligations to the many gentlemen who have generously aided me in my work.

'Without their assistance I should have been quite unable to accomplish the little that I have done. In Ireland I am indebted especially to Professor Hull, Mr. Close, Professor Valentine Ball, Mr. Kinahan, and Mr. Wynne, who have given me maps and documents of all kinds, to say nothing of personal assistance.

'In England, Professor Geikie, Professor Bonney, Professor Judd, and Professor Green, Mr. Whitaker, Mr. De Rance, Mr. Topley, and Dr. Crosskey are among those to whom I am particularly indebted.

'Many other gentlemen in all parts of England, as well as in Scotland, have rendered great assistance; among these are Mr. Morton of Liverpool, Mr. Davis of Halifax, and Mr. Eddy of Skipton.

'Not least among the advantages accruing from these investigations are the many personal friends I have gained, and I am now bound by such a strong and affectionate tie to this country as can never be lessened.

'Of the skill and accuracy of the work of British geologists I cannot speak too highly, and that I may tread humbly in their footsteps is my sincere wish.'

The friends not mentioned in this passage will kindly understand that they were, one and all, duly remembered. In his descriptions of every district he visited he very gratefully records the names of all those who placed their services at his disposal. He was accustomed to say that he never met anyone who was not willing to help him, and I could frequently see how deeply he was touched by the manifest signs of personal attachment with which he was ever greeted.

Professor Lewis, indeed, so charmed all who met him with the graciousness and beauty of his character, that *they* will read these imperfect records of his work with an interest of peculiar intensity, while the sad and early close of his earthly career will give a certain pathos to the slightest details they contain.

Those who knew him not, and who may read this volume simply as geologists, will, it is believed, find that they are in the company of one who 'walked with nature' as a humble and loving student with singular fidelity, striving to describe what he saw, and having no other interest at heart save the discovery of what is true, both for the sake of science itself, and for the enrichment of human life in its highest and noblest interests.

HENRY W. CROSSKEY.

117 Gough Road, Birmingham.

THE GLACIAL GEOLOGY

OF

GREAT BRITAIN AND IRELAND

I

COMPARATIVE STUDIES UPON THE GLACIATION OF NORTH AMERICA, GREAT BRITAIN, AND IRELAND[1]

OBSERVATIONS extending over several years upon glacial phenomena on both sides of the Atlantic have convinced me of the essential identity of these phenomena; and the object of this paper is to show that the glacial deposits of Great Britain and Ireland, like those of America, may be interpreted most satisfactorily by considering them with reference to a series of great *terminal moraines*, which both define confluent lobes of ice and often mark the line separating the glaciated from the non-glaciated areas.

It is necessary, in the first place, to describe the results of certain recent investigations upon the glaciation of North America, with special reference to the significance of the terminal moraines discovered within the last few years.

Although ever since the papers of Agassiz there have been numerous publications upon the glaciation of America, it is only within the last ten years that, by the precise mapping of the glaciated as distinguished from the non-

---

[1] Read in Birmingham before the Geological Section of the British Association for the Advancement of Science, September 4, 1886. The rough condition of the MS. of this paper has been mentioned in the Introduction.

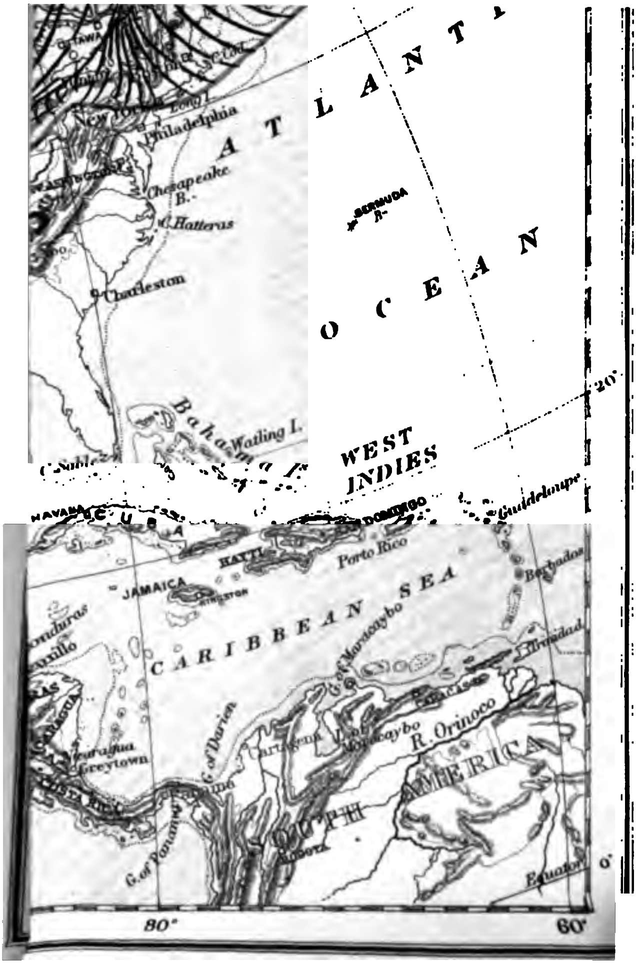
17

were pointed out and its conjectured course across t country sketched. He showed that at one period (n necessarily that of the greatest extension of the glacie great lobes of ice formed its southern boundary, and pr duced terminal moraines of great extent, forming noticeab features in the landscape. The 'Leaf Hills' in Minnesot described by Winchell and Upham, form the continuation the 'Kettle Range' of Wisconsin; while outside of thes forming an older terminal moraine, lies that remarkabl feature of the western prairies known as the Coteau de Prairies. Still farther north-west is an immense series o drift ridges, sometimes 30 miles broad and 200 feet high, which, heaped up on the cretaceous strata and 2,500 fee above the sea, is known as the Coteau de Missouri, an extends far up into British America to the head-waters of the Saskatchewan River.

Other explorations showed that these moraines probably formed a continuous series across the country; and, as recent investigations indicate, a continuous moraine, disposed in a series of great loops, extending from eastern Dakota through Iowa, Wisconsin, Indiana, and Ohio, and joining the moraine in Pennsylvania. West of Pennsylvania scattered boulders and other drifts extend for many miles in front of the line of drift hills constituting the moraine proper; but, unlike the moraine in Pennsylvania, the western drift hills are largely composed of water-worn materials, being probably similar to some of the kame-like sandy ridges found in northern Pennsylvania and central New York.

(*A map was exhibited showing the extent of the glaciated area in North America, the course of the interlobate and terminal moraines, and the direction of striation and glacial movement. This map is reproduced at p.* 5).

The facts show that apart from the great ice-sheet of north-eastern America, an immense lobe of ice descended from Alaska to Vancouver's Island, on the western side of the Rocky Mountains; and that from various separate


New York
Long I.
Philadelphia
Chesapeake B.
C. Hatteras
Charleston
A T L A N T I
O C E A N
BERMUDA R.
Bahama Is.
Watling I.
WEST INDIES
HAVANA
C U B A
HAYTI
SAN DOMINGO
Porto Rico
Guadeloupe
Barbados
JAMAICA
KINGSTON
CARIBBEAN SEA
Honduras
Truxillo
Nicaragua
Greytown
COSTA RICA
G. of Darien
G. of Panama
G. of Maracaybo
L. of Maracaybo
Cartagena
CARACAS
Trinidad
R. Orinoco
SOUTH AMERICA
BOGOTA
Equator
20°
0°
80°
60°

centres in the Cascade, Sierra Nevada, and Rocky Mountains, smaller local glaciers radiated.

The mountains encircling the depression of Hudson's Bay seem to have been the principal source of the glaciers which became confluent to form the great ice-sheet. The ice travelled south-west and east from Hudson's Bay as a centre, filling in and overflowing a low area surrounded by higher land.

In its advance the ice-sheet probably met and amalgamated with a number of already existing local glacial systems, and one centre of glaciation after another was swallowed up and made to conform to it. The White Mountains, the Adirondacks, and the Catskills were all absorbed and covered, and the glaciers issuing from them coalesced. The movements of the ice tongues which were formed by coalescing glaciers were necessarily influenced by the special circumstances connected with the various local centres of glaciation. The direction of the striæ and the direction along which transported boulders have travelled, it must be noted, always coincide.

If the great ice-sheet advanced in this way, it would increase by additions to its edges; and there is no necessity for assuming either an extraordinary thickness of ice at the Pole, or great and unequal elevations and depressions of the land, although the glacial epoch *may* have been brought on by a certain amount of elevation in the depressed northern area.

IRELAND

Detailed studies made in Ireland in 1885 show glacial phenomena remarkably similar to those in North America.

The large ice-sheet which covered the greater part of Ireland was also composed of confluent glaciers, while distinct and local glacial systems occurred in the non-glaciated area. The principal ice sheet, again, resembled that of America in having for its centre a great inland depression surrounded by a rim of mountains.

These mountains appear to have given rise to the first glaciers, which, after uniting, poured outwards in all directions.

Great lobes from this ice-sheet flowed westward, out of the Shannon, and out of Galway, Clew, Sligo, and Donegal Bays; northward, out of Loughs Swilly and Foyle; and south-eastward, out of Dundalk and Dublin Bays; while to the south the ice-sheet abutted against the Mullaghareik, Galty and Wicklow Mountains, or died out in the plains.

Whether it stopped among the mountains or in the lowlands, its edge was approximately outlined by unusual accumulations of drift and boulders representing the terminal moraine. As in America, this terminal moraine was least distinct in the lowlands, and was often bordered by an outer fringe of drift several miles in width.

South of an east and west line extending from Tralee to Wexford is a non-glaciated zone free from drift.

Several local systems of glaciers occur in the south of Ireland, of which by far the most important is that radiating from the Killarney Mountains, covering an area of 2,000 square miles, and entitled to be called a local ice-sheet.

Great glaciers from this Killarney ice-sheet flowed out from the fiord-like parallel bays which indent the south-western coast of Ireland.

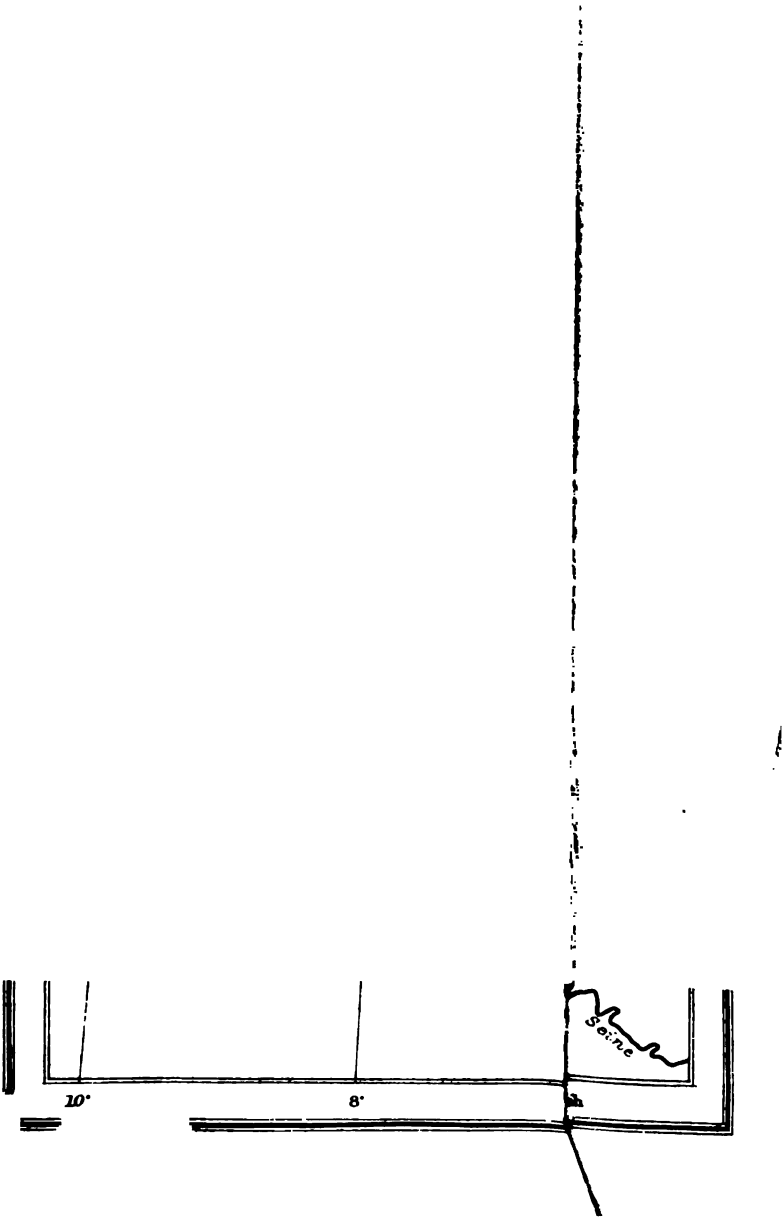
At the same time the Dingle Mountains, the Knockmealdon, and Commeragh Mountains, and those of Wexford and Wicklow, furnished small separate glaciers, each sharply defined by its own moraine.

No evidence of any great marine submergence has been discovered.

The eskers do not prove marine submergence, since their phenomena can be accounted for by the melting of the ice and the circulation of sub-glacial waters.

The Irish ice-sheet seems to have been joined at its north-eastern corner by ice coming southward from Scotland across the North Channel.

[illegible] BRITAIN



All the evidence collected indicates that a mass of Scotch ice, reinforced by that of Ireland and England, filled the Irish Sea, overriding the Isle of Man and Anglesey, and extending at least as far south as Bray Head, south of Dublin.

(A map of the glaciation of Ireland was exhibited, in which the observations of the Irish geologists and of the author were combined, and on which the central ice-sheet, the five local glacial systems, all the known striæ, and the probable lines of movement as indicated by moraines, striæ, and the transport of erratics were shown.)

WALES

Wales supported three distinct and disconnected systems of local glaciers; while, at the same time, its extreme northern border was touched by the great ice-lobe of the Irish Sea. The most extensive local glaciers were those radiating from the Snowdon and Arenig region; while another set of glaciers radiated from the Plynlimon district and the mountains of Cardiganshire; and a third system originated among the Brecknockshire Beacons.

The ice-streams from each of these centres transported purely local boulders, and formed well-defined terminal moraines. Some illustrative facts may be given.

Great glaciers descended both the north and south sides of Aran Mawddwy,[1] and flowed down in a wide stream across Bala Lake, east of which, being joined by a still larger glacier proceeding from the Arenigs, the united streams flowed east-north-east, along the valley of the Dee, past Corwen, and then toward the east to Llangollen, where they heaped up a mighty moraine, which filled not only the valley, but stretched up and across the hills both west and south of Llangollen to at least 1,100 feet.[2]

---

[1] Vide *Ramsay's Geology of North Wales*, p. 316.

[2] Vide 'Additional Remarks on Boulders,' by D. Mackintosh, F.G.S. *Quart. Journ. Geol. Soc.* 1874, passim.

Striæ mark its passage at various points, not only about Bala, but on the hill south of Corwen (to east-north-east — Mackintosh), and north of Glyndyfrdwy (same direction), and at Llangollen (to the east); but here is the moraine, and east of this point no striæ occur (according to Mackintosh).

The moraine is crowded with boulders of felspathic trap from the Arenigs. Mr. Mackintosh remarks that the boulders are 'the largest and most numerous near to, or approaching, their greatest distance from their parent rocks'; although here, as elsewhere, he fails to perceive the true meaning of this fact, and endeavours to explain it by floating ice.

The moraine of this ice-sheet is well marked, not only in the valley of the Dee, but on the high plateau, five miles north of Llangollen, above the gorge called the World's End, where it rises up to 1,830 feet, as well as south of Llangollen at least as far as the Grouse-box Hill. Huge boulders mark its presence, the largest of which lies west of Cefn, and measures 15 feet × 14 feet × 10 feet in its exposed part, and consists of felsite.

Mr. Mackintosh's observations show that another great ice-stream, proceeding from the Arenigs, flowed east-north-east to Llanarmon, where again is a fine moraine, marked by huge boulders. One of these boulders (a felstone), situated north of St. David's Church, Eryrys, measures 15 feet × 15 feet × 12 feet, and is 1,123 feet above the sea.

This 'terminal concentration' of felspathic boulders reaches upon Moel-Fammau to the north, and on the high hills to the east of Llanarmon to the height of at least 1,200 feet, so that, as in the Llangollen district, the boulders have been moved uphill.

Each of these ice-streams was at least twenty-five miles in length, and over 1,000 feet in depth.

The northern ice-lobe, bearing granite boulders from Scotland, and shells and flints from the bed of the Irish

Sea, invaded the northern coast of Wales, but did not mix with the local systems of glaciers.

Flint-bearing gravel (*Ramsay's Geol. of N. Wales*, p. 276) and granite blocks occur on the seaward slope of Moel Wnion up to 800 feet. The flints must have come from the Irish Sea.

Sir Andrew Ramsay has traced the course of the northern ice-sheet quite closely along the northern and western sides of Wales, and Mr. Strahan has done the same thing (*Quart. Journ. Geol. Soc.*, 1885), although coming to conclusions which I believe to be untenable.

Sir Andrew describes a great ice-stream which, composed of glaciers coming from Cumberland and Scotland, filled the eastern part of the Irish Sea, and impinged upon North Wales so as to bury Great Ormes Head, Little Ormes Head, and Deganwy (all finely moutonnée), and pressing along the slopes of Llanfairfechan, the lower end of Aber Valley, the seaward flank of Moel Wnion, and across the lower end of the valley of the Ogwen, overspread all Anglesey, the Menai Straits and the minor hills between the mountains of Carnarvonshire and the sea (*Geol. of N. Wales*, p. 273).

It then passed up the western flank of Moel Tryfaen, where, at 1,350 feet above the sea, is an unstratified boulder clay, containing chalk flint, with granite and other northern rocks.

Immediately beneath this boulder clay occur the well-known shell-bearing sands and gravels first described by Mr. Joshua Trimmer in 1831 (*Proc. Geol. Soc.*, vol. i. p. 33), and supposed by him and most subsequent geologists to be proofs of marine submergence.

The meaning of these false-bedded sands and gravels, with their fragmentary shell remains, will be discussed in a subsequent part of this paper.

The direction of the glaciation in Anglesey is marked not only by striæ but by the transported boulders.

No rocks from the Welsh mainland occur among the

Anglesey boulders, but rocks from Cumberland and Scotland, together with chalk flints. Occasionally, as in the cliff of till at Beaumaris, shell fragments are found.

Moreover, the rocks of Anglesey itself have been transported in the same direction as that along which the erratics must have travelled. There is one well-marked rock which offers unquestionable evidence of this fact. I refer to the hornblende picrite, the structure of which has been so well described by Professor Bonney (*Quart. Journ. Geol. Soc.* 1883, p. 254). This rock was at first thought to belong to the Lake District, but Professor Hughes discovered it *in situ* in two places in the middle of Anglesey, each lying slightly to the north of north-east of the district over which the boulders are scattered (*Quart. Journ. Geol. Soc.*, 1885, p. 515) a direction precisely corresponding to that of the striæ, which run from N. 35° E. to S. 35° W. (*Ramsay's Geol. of North Wales*, p. 270).

The erratic fragments of Lake District rocks referred to by Mr. Teall, Mr. De Rance, Mr. Mackintosh, Mr. Strahan, Sir A. Ramsay, and others, as occurring in Eastern Wales, are all such as lay directly in the path of the great ice-tongue which stretched from the Lake District to East Wales.

Anglesey and Carnarvonshire did not receive Lake District rocks, but lay in the path of the yet larger ice-tongue which came from Scotland across the Solway Firth. Criffel granite was carried by that large tongue and dropped on the Isle of Man, on Anglesey, on Moel Tryfaen, and as far south as the extremity of the Lleyn peninsula at Aberdaron Bay (*Ramsay's Geol. of North Wales*, p. 211), where boulders of granite clearly from the Criffel district (although containing large porphyritic crystals resembling those in the Shap granite) are found.[1]

The facts, so far as they appear to me to be ascertained, regarding this great northern ice lobe, may be summed up as follows:

---

[1] This account of the distribution of the Criffel granite is evidently not given from Professor Lewis' own observations, and a re-examination of the specimens is required before it can be accepted. The passage is retained, however, as raising a question for further inquiry.—H. W. C.

It smothered Anglesey and part of Carnarvonshire on the one side, and part of Flintshire on the other, and heaped up a terminal moraine on the outer flanks of the North Welsh mountains. This great moraine, filled with far-travelled northern erratics, is heaped up in hummocks and irregular ridges, and is in many places as characteristically developed as any moraine in America. It has none of the characteristics of a sea-beach, although often containing broken shells brought from the Irish Sea.

It may be followed from the extreme end of the Lleyn peninsula (where it is full of Scotch granite erratics) in a north-easterly direction, through Carnarvonshire, past Moel Tryfaen, and along the foot of the mountains east of the Menai Straits to Bangor, where it goes out to sea, reappearing farther east at Conway and Colwyn. It then turns south-eastward to Denbighshire, going past St. Asaph and Halkin Mountain.

In Flintshire it turns southward, and is magnificently developed on the eastern side of the mountains, at an elevation of over 1,000 feet between Minera and Llangollen, south-west of which place it enters England.

There is evidence that where this ice-sheet abutted against Wales it was about 1,350 feet in thickness.

This is analogous to the thickness of the ice-sheet in Pennsylvania, where I have shown that it was about 1,000 feet in thickness at its extreme edge and 2,000 feet thick at points some eight miles behind it. The transport of erratics coincides with the direction of the striæ in Wales as elsewhere, and is at right angles to the terminal moraines.

ENGLAND

The complicated phenomena of the glaciation of England have been the subject of a voluminous literature and discordant views.

Facts gathered directly from the field have, however, convinced me that it is possible accurately to map the glaciated areas; to separate the deposits made by land-ice from those due either to icebergs or to torrential rivers; and to trace out a series of terminal moraines both at the edge of the ice-sheet and at the edges of the confluent lobes.

Perhaps the finest example of a terminal moraine in England is in the vicinity of Ellesmere, in Shropshire. A great mass of drift several miles in width, and full of erratics from Scotland and from Wales, is here heaped into conical hills which enclose 'kettle-holes' and lakes, and have all the characters of the 'Kettle Moraine' of Wisconsin. Like the latter, the Ellesmere moraine divides two great lobes of ice. Of these lobes, one came from Scotland, the other from Wales. This moraine may be traced continuously from Ellesmere eastward, through Madeley, Macclesfield, to and along the western flank of the Pennine Chain, marking throughout the southern edge of the ice-sheet of northern England.

From Macclesfield I traced the same moraine past Stockport and Staleybridge to Burnley, and thence to Skipton in Yorkshire.

North-east of Burnley it is banked against the Boulsworth Hills up to a height of 1,300 feet, in the form of mounds and hummocks.

South and east of this long moraine no signs of glaciation were discovered, while north and west of it there is every evidence of a continuous ice-sheet covering land and sea alike.

The striæ and the transport of boulders agree in proving a southerly and south-easterly direction of ice-movement in Lancashire and Cheshire.

From Skipton northward the phenomena are more complicated.

A tongue of ice surmounted the water-shed near Skipton, and protruded down the valley of the Aire as far as Bingley, where its terminal moraine is thrown across the valley like a great dam, reminding one of similar moraine dams in several Pennsylvanian valleys. A continuous moraine was traced around this Aire glacier.

Another glacier much larger than this descended Wensleydale and reached the plain of York.

The most complex glacial movements in England occurred in the mountain region about the Nine Standards, where local glaciers met and were overpowered by the greater ice-sheet coming down from Cumberland. The ice-sheet itself was here divided, one portion going southward; the other, in company with local glaciers and laden with the well-known boulders of 'Shap granite,' being forced eastward across Stainmoor Forest into Durham and Yorkshire, finally meeting the North Sea at the mouth of the Tees.

The terminal moraine runs eastward, through Kirkby Ravensworth toward Whitby, keeping north of the Cleveland Hills; and all eastern England south of Whitby appears to be non-glaciated.

On the other hand, all England north of Stainmoor Forest and the river Tees, except the very highest points, was smothered in a sea of solid ice.

THICKNESS OF THE ICE

Beginning with the northern part of England, it can be proved that the ice there was about 4,000 feet thick.

Measuring north from Whitchurch (Shropshire), we find that at a distance of 130 miles back from the edge of the ice-tongue it was thick enough to surmount mountains in the Lake District 3,600 feet high, and to striate them on their summits.

Farther south, at Stainmoor Forest and Baugh Fell, the ice covered ground 2,200 feet above the sea; but at the head-waters of the Ribble about Wharnside it could not get across peaks rising to 2,400 feet (Goodchild, Tiddeman, &c.)

Between Skipton and Burnley the ice of the main mass rose to only 1,250 feet on Boulsworth Hill. At Pendle Hill it did not get higher than about 1,000 feet; but near Bolton it rode over land 1,380 feet above sea-level.

Thus the ice was thicker in the middle than at the edges; and the main stream which flowed through Lancaster, Bolton, and Manchester was thicker than the lateral and tributary confluent glaciers which started in the high mountains between Wharnside and the Nine Standards. This is precisely what may be seen in a modern Swiss glacier—it is bulged up in the middle.

Following the ice-sheet yet farther south, we find it lapping over the ridge east of Macclesfield to the height of 1,350 feet. On the Welsh side, west of Ruabon, it rises to 1,350 feet, but *not* to 1,500 feet (Mackintosh); when abutting against the mountains on the north coast, to about 1,000 feet; on the west side, at Moel Tryfaen, to 1,350 feet; but south of this last-named point it was not so thick.

We thus perceive a gradual diminution in the thickness of the ice-sheet, from 4,000 feet at a point 130 miles distant from its terminal moraine to 1,000 feet at its end.

Let me mention two analogous cases, one in Ireland, and one in America:

A glacier starting in the district south-east of Killarney has deposited erratics at 2,950 feet in its upper part; and in its southern course at the successive levels of 1,500 feet, 1,270 feet, and 1,000 feet.

An enormous glacial tongue descended the Hudson River Valley in America, and striated mountains in the Catskill range 3,100 feet high, across their summits; while in Pennsylvania fifteen miles north of its southern limit it did not surmount peaks higher than 2,000 feet, and at its edge was not more than 800 feet thick. In certain valleys, indeed, the extreme edge of the ice was only about 700 feet thick, becoming nearly double that thickness within a mile of its edge, and five miles back from the edge it was at least 1,000 feet thick.[1]

With respect to the ice-lobe filling the Irish Sea, there is abundant evidence to prove that it was thicker toward its axis than at its edges; at the north rather than at its terminus; and that it was reinforced by smaller tributary ice-streams from both England and Ireland. It may be compared with the glacier of the Hudson River Valley, just described, each having a maximum thickness of something more than 3,000 feet.

Compare the thickness of the Irish Channel ice-sheet with that of the old glaciers of Switzerland. We find that the great Alpine valleys are striated on their sides up to 4,000 feet above the present ice-streams; and that boulders have been landed on the slopes of the distant Jura 2,000 feet above the plain.

The *erosive power* of the ice-sheet I have found to be extremely slight at its edge, but more powerful farther north, where its action was continued for a longer period. Towards its edge, its function was to fill up inequalities rather than to level them down.

I proceed to another and most important point.

Has there been a *great* submergence in any part of Great Britain during the glacial epoch?

Notwithstanding the general opinion to the contrary, I hold that no satisfactory proof is to be found in Great Britain of any marine submergence during the glacial epoch, greater than about 450 feet.[2]

Marine shells have undoubtedly been discovered in glacial clays, sands and gravels, at various localities, in England, Wales, Ireland, and Scotland; and it is assumed that these shells prove the submergence of the land beneath a sea which deposited them in the beds in which they now occur.

---

[1] 'Report Z.'

[2] In a subsequent paper it will be seen that Professor Lewis still further limits the marine submergence of Great Britain during the glacial epoch, and states that there is little doubt of a submergence of about 100 feet on the east coast and 150 feet on the west coast of England. A general account of his views has been given in the Introduction. (See pp. 65, 253 and 254.)

Is this assumption justified?

The high-level shell beds are those to which special attention must be directed; and of these remarkable examples present themselves in Ireland, Wales, and England.

The elevated shell-bearing gravels near Dublin have been described by the Rev. Maxwell H. Close, M.A.[1] These gravels are in the vicinity of the hill mass, the best known of whose prominences is named the Three Rock Mountain, part of the north-east end of the Wexford, Wicklow, and Dublin granite range; and marine shells have been found in them at an elevation of a little over 1,200 feet.

Mention has already been made of the Moel Tryfaen shell beds. The highest point at which shells have been found in these beds is 1,370 feet.[2]

In the district about Macclesfield, shell beds have been found, and in one locality attain an elevation of 1,100 to 1,200 feet above the sea.[3] Mr. De Rance has informed me that shells occur in the drift some six miles east of Keswick at an elevation of about 600 feet. In Scotland no marine shells have been discovered at heights corresponding to those of some of the deposits in Ireland, Wales, and England; but Mr. Jamieson (*Quart. Journ. Geol. Soc.*, 1874, p. 317) remarks that shells occur in the drift at the northern extremity of Aberdeenshire, at elevations of nearly 500 feet.

---

[1] 'The Elevated Shell-bearing Gravels near Dublin,' by the Rev. Maxwell H. Close, M.A., F.G.S., *Geol. Mag.* Decade II. vol. i. No. 5, May 1874.

[2] Darbishire, *Proceed. Manchester Lit. and Phil. Soc.* 1863–4.

[3] A paper 'On the Genuineness of certain Fossils from the Macclesfield Driftbeds,' by R. D. Darbishire, M.A., F.G.S., *Geol. Mag.* No. XIII., July 1865. 'Notes on Marine Shells found in stratified Drift near Macclesfield,' by R. D. Darbishire, M.A., F.G.S., third series, *Memoirs of Lit. and Phil. Soc. of Manchester*, 1864–5.

A bed near Airdrie,[1] at an elevation of 526 feet, containing *Tellina calcarea*, was first announced by Mr. Smith, of Jordan Hill, in 1850, and was afterwards described by Dr. Crosskey (*Quart. Journ. Geol. Soc.*, 1865, p. 219), and mentioned by Dr. J. Geikie in his *Great Ice Age* (2nd ed. pp. 163, 175), and all these geologists regard it as a marine deposit, and as proof of a submergence of at least 550 feet.

I examined Dr. Crosskey's collection of shells from the low-level marine clays in the districts that surround the present course of the Clyde, and which have been described by him and Mr. Robertson in the *Proceedings of the Geological Society of Glasgow* (vols. ii. iii. iv. and v.) and I saw at once that they were entirely different in character from the broken and fragmentary specimens obtained from Macclesfield and Moel Tryfaen.

I believe it to be quite impossible to explain these various high-level shell-bearing masses of clay and gravel

---

[1] My collection does not contain any specimens from the Airdrie beds, but I was able to show Professor Lewis perfect and unworn shells from the clay bed at Clava on the east side of the river Nairn, about six miles due east of Inverness, and 502 feet above the sea-level. This bed was discovered by Mr. G. Fraser, C.E., and has been very accurately described by him in the *Transactions of the Edinburgh Geological Society*, vol. iv. p. 136. It is alluded to by Professor Lewis in his Note Books. I have examined it and can entertain no doubt that the shell clay is *in situ*. The section is:

	Feet
Soil and gravelly subsoil	about 5
Boulder clay	40 to 45
Fine sand, stratified	2
Shell bed of blue clay, bottom not reached	7½

The fine stratified sand rests upon the blue clay and is not intermixed with it. It was evidently quietly deposited. The clay contains seventeen species of mollusca, some of a highly Arctic type, and all of an Arctic range, together with nine species of Orthocoda characteristic of Arctic clays, and is quite undisturbed. Professor Lewis in a pencil note in his MS. writes: 'How about the shells at Inverness? Answer; they are pre-glacial.' When, in conversation upon the subject, I urged that it was quite impossible to differentiate this high-level shell clay from the shell clays of lower levels, he suggested that the north of Scotland might have been submerged without a corresponding submergence having taken place in England.—H. W. C.

and sand, except by the hypothesis that they were carried by an ice-sheet to their present position.

It was to be expected that an ice-sheet advancing across a sea should deposit shell fragments in its terminal moraine; and I hold, as a broad principle, that wherever in Great Britain marine shells occur in glacial deposits at high levels, it can be proved, both by striæ and the transport of erratics, that the ice advanced on to the land from out of the sea.

The occurrence of moraines within 150 feet of the sea must be noted as facts opposed to the theory of submergence. Such moraines (as Mr. Kinahan has remarked, *Proc. Geol. Soc.*, Dublin, 1860) could never have been under water—the sea would have washed them away.

Take the case of the 600 feet shell bed near Keswick; Criffel boulders occur in the same district, and the striæ run north-west and south-east, proving that an ice-sheet advanced from Scotland across the Solway Firth to the Lake District. By this ice-sheet, therefore, the shells would be transported to their present position.

Shells occur in the till at the mouth of the Tyne, associated with stones of northern origin, and have evidently been pushed up out of the sea with the stones.

With respect to the Airdrie district, an examination of the mass of striæ given in Geikie's *Great Ice Age* shows that this was one of the few places in Scotland where the ice advanced on to the land from the sea. The striæ plainly indicate that a mass of ice was forced up the river Clyde from the direction of Greenock to Glasgow, and thence passed eastward towards the Firth of Forth, thus going completely across Scotland.

Clearly this ice-tongue gathered up shells out of the bed of the Clyde and carried them inland.

The researches of Mr. Jamieson, Dr. Croll (*Climate and Time*, p. 453), Professor A. Geikie, and Mr. Peach have shown that the Scotch till contains shells only where the ice-sheet advanced from the sea. So it is at Peterhead, where the ice has advanced out of the Moray Firth; at

Berwick, where it has advanced out of the Firth of Forth; on the coast of Wigtownshire near the Mull of Galloway, where it has come across the Bay of Luce; and in the Isles of Arran and Lewis, where it has also come from the sea.

There is no reason to suppose that the shells on Three Rock Mountain and Moel Tryfaen, and at Macclesfield, were not deposited in the same way.

A glacier in its advance has the power of raising stones from the bottom to the top of the ice, a fact due to the retardation by friction of its lower layers. I have observed the gradual upward passage of sand and stones in the Grindelwald glacier, and the power of the glacier to effect this upward passage of material accumulated in its lower layers is, I believe, sufficient to explain the presence of broken shells and flints at high levels.

If there has been a great submergence, how is it that deposits corresponding to the high-level beds that have been described are not found in other parts of Great Britain?

Mr. Trimmer, the discoverer of the Moel Tryfaen shells, was not able to overlook the remarkable fact that there is an absence of marine remains over the greater part of Britain (*Quart. Journ. Geol. Soc.*, 1850, p. 214).

Mr. Jamieson (*Quart. Journ. Geol. Soc.*, 1887, p. 320) supposes the absence of marine beds over the greater part of Scotland to be due to the subsequent occupation of the country by an ice-sheet; but he admits that no proof of such a second ice-sheet is to be found. Marine shells in Scotland, except in a few places near the coasts and elsewhere, where the ice advanced from the sea, are entirely absent, even in valleys at low levels (*loc. cit.*).

The same difficulty of explaining why marine beds should occur in the precise places in which they are found, *and not in others*, has presented itself to Dr. Scouler (*Journ. Geol. Soc.* Dublin, i. 266) and to Mr. Oldham (*ibid.* iii. p. 202) in discussing the Irish deposits. They observed that although shell drift was piled high up against the Wicklow Mountains, the glens close by and the low ground about

Dublin were completely free from any marine beds. It was suggested, however, that the shell beds are more ancient than the rest of the drift, and possibly more ancient than the ravines.

The occurrence of stratified deposits in connection with undoubted moraines, at high as well as low levels, has been relied upon as favouring the submergence theory. But this is a common phenomenon in the formation of moraines. Instances of stratified moraines may be seen in Switzerland, Italy, and America. The stratification is due to waters derived from melting ice, and is not a proof of submergence.

The evidence for more than one advance of the ice-sheet appears to me as insufficient, as it is for successive elevations and submergences, with several advances and retreats of the ice-sheet; and much of the supposed 'inter-glacial' drift I believe to have been due to subglacial water produced by melting ice.

The distribution of boulders, gravels, and clays south of the glacial area shows, I think, that by far the larger part of England was not covered by land-ice.

The drift deposits south of the glacial area were the result in part of great fresh-water streams issuing from the melting ice-sheet; and in part of marine currents leaving icebergs during a subsidence of some 450 feet.

Large rivers issued from the great ice-sheet and the melting glaciers of Wales, which flowed south and south-east until they joined the greater stream which covered that part of England lying below the 300 feet level, and flowed south-west.

The courses of these rivers may be traced. Three streams came together near Birmingham. The largest of these, starting at Ellesmere and Whitchurch, flowed south to Wolverhampton—the first high ground it met—and dropped its boulders of Lake and Criffel origin; its further southward course, marked by few boulders, being in the valley of the Severn.

The second and much smaller river followed the valley of the Trent, and, keeping east of the first stream, approached Birmingham by another course.

A third river at a higher level than either of the others drew its waters from the great Welsh glacier which stretched from the Arenigs to Llangollen. It headed somewhere near Oswestry; swept past the Wrekin and followed the valley of the Severn, being perhaps joined by another great river issuing from Wales near Montgomery.

The supposed glacial drift about Birmingham and the concentration of boulders about Wolverhampton were due to these great fresh-water streams.

On the other hand, the deposits at Cromer and the distribution of Lincolnshire chalk across southern England were due to marine currents bearing icebergs. The supposed esker at Hunstanton is simply a sea-beach; and the London 'drift' deposits are of aqueous origin.

Thus the rival theories of floating icebergs and of land glaciers are both true; the former for middle and southern England; the latter for Scotland, Wales, and the north of England; and the line of demarcation is fixed by great terminal moraines.

II

THE TERMINAL MORAINES OF THE GREAT GLACIERS OF ENGLAND [1]

It is well known to every geologist that formerly, when the glaciers of Switzerland were much larger than they are at present, the Rhone glacier, now only six miles in length, was at least 175 miles long: and had a thickness in the Rhone Valley of over 4,000 feet. It flowed out to the Jura, and dividing at the Lake of Geneva, one branch passed north-east, and another south-west to Lyons, having a thickness of 1,000 feet at its termination.

It is likewise well known that in America, at the same period, a glacier, now entirely extinct, flowed down the Hudson River from Montreal to New York, being over 300 miles long, at least 4,000 feet thick in the lower half of its course, and much thicker farther north, where it was confluent with other glaciers.

It is also well proven that, at that time, a similar large glacier filled the bed of the Baltic, from Lapland to Prussia, having a length of 1,000 miles, and a proportionate thickness.

Examples of hundreds of other equally large or larger glaciers which existed at this period might be quoted.

There is, in my opinion, entirely satisfactory evidence that the site of the present city of Manchester lay in the path of, and was covered by, a glacier which in all its proportions and properties was identical with these and similar glaciers in Europe and America, and contemporaneous with them; and I propose to describe some of the results of my investigations concerning the exact size and limits of this and other large ice-streams which existed in England at the same time.

---

[1] Read in Manchester before the Geological Section of the British Association for the Advancement of Science, September 2, 1887.

The great principle upon which I shall firmly insist, and which has served me admirably in tracing out the ancient glaciers of this and other countries, is, *that every glacier at the time of its greatest extension is bounded and limited by a terminal moraine.*

This is a principle not yet recognised by most of my fellow-geologists; but I have found it to be the veritable key to glacial geology.

When it is once acknowledged, the many phenomena of the glacial epoch which have been the cause of so much discussion in England and elsewhere at once become simple and clear.

All the complicated theories of recurring glacial periods, of submergences and elevations, of alternating heat and cold, &c., are swept away, and we find that we have to deal with simple glaciers, which were made by the same causes that make glaciers now, which moved in the same way as they move now, and accumulated precisely the same kind of deposits as those which now result from the work of ice. That, in short, in the glacial period, as at present, nature has been acting uniformly and according to law.

I had the honour of speaking of the terminal moraines of the American glaciers at the last meeting of the British Association, and I merely repeat that, where I have followed them, they form the precise limits of glaciation;[1] and that the boulder clay and gravels outside of these moraines can be explained as the result of floating ice and flowing water.

The Baltic glacier is also bounded by a great moraine extending across North Germany.

---

[1] Namely, of the solid ice.

In Switzerland it is curious to find that the geologists, with one accord, deny that the ancient Rhone glacier was bounded by a moraine; although admitting that the Aar glacier, the Reuss glacier, the Rhine glacier, &c., all had their well-marked terminal and lateral moraines.

The supposed absence of any moraine to the largest glacier in Switzerland is explained by saying that it was too large to have had a moraine, having been practically an ice-sheet which covered everything.

This being assumed, and a convenient explanation being wanted for certain gravels which underlie the ordinary till and continue beyond it, another and earlier ice-sheet is supposed to have extended north and south of Switzerland, which was also devoid of a terminal moraine, and belonged to a so-called first glacial epoch.

Before attempting to define the English glaciers by their moraines, it is absolutely necessary to know whether it is true: (1) that the Rhone glacier had no moraine; (2) that the glaciers of the so-called first glacial epoch had no moraines.

I have, therefore, spent the present summer in studying these two questions, and after several months of field work am convinced that neither of these propositions can be sustained.

With all deference to the distinguished observers who have preceded me in Switzerland, I am compelled to disagree with them, having found: (1) that a great terminal moraine continuously bounded the Rhone glacier at the time of its greatest extension; and (2) that this moraine was made at the time of the first and only glacial epoch.

The moraine is well marked on both sides of the glacier, and I examined it at many points. It is as typically developed as the moraine of any glacier in Switzerland, or as the moraines of the glaciers which together formed the great ice-sheet of North-East America.

Where this moraine lies on the flanks of the Jura, it is characterised by an abundance of large blocks, including erratics, and by deep masses of true glacial till; while on the south side of the great glacier it is heaped up in ridges and conical hills, and often encloses typical moraine meres.

The moraines on each side of the glacier are at about equal heights when opposite to each other, and diminish gradually in altitude as they go from its source to its end.

With regard to the assumption of an earlier glacial epoch in which a glacier of unknown dimensions was bounded by no moraine, I found no evidence to justify it.

The gravels which in many places underlie the glacial till are clearly not the product of a glacier, but are river and lake deposits, made purely by water.

These deposits are usually compacted into a more or less hard conglomerate, the pebbles of which are well water-worn, and have not the shape of glacial material.

Again, a number of water and iceberg carried deposits outside of the terminal moraines—some of them pre-glacial, and some of them made in lakes dammed up by the glaciers—have been confusedly classed together as belonging to the glacial epoch, and proving an ice-sheet, although the regions in which they occur show no traces of ice-action.

The lignite beds of Utznach and Dürnten, supposed to indicate a warm inter-glacial epoch, are, in reality, pre-glacial, and correspond with the pre-glacial forest bed of the coast of Norfolk, of quaternary or pleistocene age.

Of variations in the glacial epoch, of step-like advances and retreats of the old glaciers as well as the present ones, there is plenty of evidence; but of more than one great extension of the ice, or of any extension beyond the terminal moraines, I found no trace.

It has also been stated that the Black Forest was covered by an ice-sheet of indefinite boundaries. I found, however, that the glaciers of the Black Forest were small, and were as precisely limited by moraines as are the glaciers of the Vosges, of Wales, of Killarney in Ireland, and of the Rocky Mountains of America.

Strengthened, therefore, by my observations in Switzerland and the Black Forest, I return with renewed confidence to my proposition that *all glaciers are bounded and limited by terminal moraines*, and proceed at once to the consideration of the great British glaciers which form the main subject of this paper.

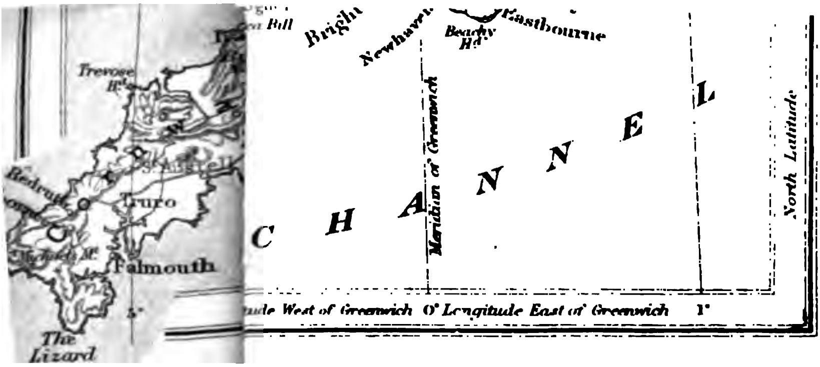
The largest of these glaciers was one which, starting in the west of Norway, north of Christiania, at first flowed south and then south-west out of the Skager Rack, and across part of Jutland into the North Sea, where it was joined by other great glacial streams coming from Norway and Scotland, until the North Sea was completely filled by it. It reached the shore of England at Holderness. The limits of this large glacier are precisely defined by its terminal moraine; and the transported stones in its moraine can be as readily identified with the rocks of Norway 500 miles away, as the blocks in the Jura with the rocks about Monte Rosa.

The terminal moraine which this glacier formed, where it ended on the coast of Yorkshire, is both in form and in composition as typical a moraine as any in Switzerland. It is made of till; is full of scratched stones and Norwegian erratics; is heaped up in ridges and conical hills, including ponds and lakes; and is sometimes so massive as to completely reverse the drainage of rivers.

In the bed of the North Sea this moraine is marked by shoals which stretch from the mouth of the Rhine to the mouth of the Humber, and it contains many Norwegian erratics.

The glacier approached, but did not touch, the English coast about Cromer, where, however, icebergs from it grounded in large numbers.

Lincolnshire was not invaded by the ice except at its extreme north-western corner; Cleethorpes being the most southern point in England reached by the North Sea glacier; there for the first time in going north along the coast of England does genuine glacier-made till occur. The flat coast of Lincolnshire rises here into a cliff of till, in which

Bill
Bright
Newhaven
Beachy Hd.
Eastbourne
Trevose Hd.
St Austell
Redruth
Truro
Falmouth
The Lizard
5°
Meridian of Greenwich
C H A N N E L
North Latitude
tude West of Greenwich 0° Longitude East of Greenwich 1°

lie closely-packed, angular, and striated together with rounded stones—the angular ones having been brought mainly from the neighbouring sea-bottom, the rounded ones from a greater distance. Many of these stones have certainly come out of the Christiania fjord, and we recognise amongst them the characteristic 'Rhomben-porphyr,' the Halleflinte, the porphyrite, the red porphyritic granite, and other ancient crystalline rocks peculiar to southern Norway, as also red Danish flints. The exposure of the terminal moraine is here very limited, almost all of it having been washed away by the continually encroaching sea.

On the north side of the Humber, however, the moraine appears in force, and on the low ground of Holderness, between the mouth of the Humber and Flamborough Head, it runs inland to form a great bow, and again reaches the coast at Flamborough Head.

The moraine at Holderness is a conspicuous feature of the landscape, and formerly enclosed a multitude of small meres; most of these are now artificially drained.

Outside, on the west of the moraine in this district, are great aqueous deposits, such as those at Kelsey Hill, made in lakes and estuaries bordering the ice-cliff.

Traces of marine beaches, indicating a submergence of nearly 100 feet before the approach of the glacier, also occur in this region, as, e.g. at Craike Hill, West Driffield, outside of the moraine. The moraine itself (in the tracing of which at Holderness I had the kind aid of Mr. G. W. Lamplugh, of Bridlington) is marked as a line of drift hills passing east of Driffield, and known by different names. It is well seen at the village of Brigham. Sometimes it is composed of till, but frequently, like all other low-lying moraines in Switzerland and elsewhere, where water in front of or issuing from the ice is an important factor, it consists of stratified sand and gravel, showing torrential stratification.

I may here mention that it is a mistaken idea, although stated in most of our text-books, that moraines are necessarily unstratified. They are sometimes entirely stratified—almost as much so indeed as kames. I found in Switzerland that three kinds of moraines could be distinguished according to their structure and position.

1. Talus moraine, situated close to modern glaciers in narrow valleys; and composed of purely angular material, like talus or detritus from a mountain side, unworn by ice or water.

2. Moraine proper, terminal, lateral, or medial, made at the time of the farthest extension of the ice. In this rounded and angular blocks are mixed, but the larger proportion are glaciated.

3. Stratified moraine, consisting of sand and gravel, made in valleys or on low ground far from the modern glacier, or at the edge of glaciers where streams flowed off, or between the ice and the land, or between two glaciers from which water issued.

All possible gradations from one to the other occur.

Of stratified moraines excellent examples may be seen about Berne at the end of the Aar glacier; in connection with the Aar glacier, indeed, all three kinds may be found. About Lake Thun there are typical ice-made moraines. Farther up in the valley are talus moraines, with an abundance of angular blocks. All moraines made in water or at the edge of glaciers are quite distinct from kames, which are mainly due to marginal or subglacial rivers.

Returning to the Holderness glacier; it reached the chalk escarpment north of Bridlington; and, having been unable to surmount that escarpment, it again approached the coast at that town, and its moraine is typically exhibited north of Flamborough Head, near the village of Speeton. Here the moraine has blocked some pre-glacial river valleys; and has reversed the drainage so that the modern streams flow inland.

Northward from this point the moraine contains a predominance of English boulders; and these boulders show that we have crossed the direct ice-stream from Scandinavia, and that this section of the glacier came from a part of England north and west of the Tees. A glacier coming down the river Tees from the Pennine Chain had become confluent with the Scotch and Scandinavian glaciers in the North Sea, and was with them directed southward.

Following the terminal moraine along the coast line from Speeton through Breckton, Filey, and Scarborough to near Whitby, we find that at Scarborough it has completely choked up the river Derwent, and made it cut a new passage through the rock a mile long and flow away from the sea.

English erratics now entirely replace Norwegian ones, and boulders of Shap granite become more and more abundant as we go north, proving that we are now on the edge of the second great glacier of England. which, though much smaller than the North Sea glacier, was thick enough to flow across the Pennine Chain, being at least 100 miles long. As a matter of fact, this glacier, which we may call the Stainmoor glacier, was but an arm of the larger one, which, originating in Scotland, filled the Irish Sea as far south as Anglesey.

The great glaciers of England can be as sharply distinguished from one another as can the ancient glaciers of Switzerland by certain characteristic boulders, which both occur in the terminal moraines, and can be traced continuously along great curved lines to their sources.

Where a glacier has lateral moraines, the boulders on one side of the ice-stream may be quite unlike those on the other side; and this is one of the characteristics which distinguish glacial from aqueous, or fluviatile, or iceberg-made, deposits.

An irregular intercrossing of erratics derived from various points of the compass is one of the surest signs of iceberg and not glacial transport. This principle, which I have found so useful in Switzerland, I shall also apply to England.

The most characteristic rock of the Stainmoor glacier is the well-known Shap granite—a rock which formed a crag directly in its path, and which has been carried by it over the Stainmoor Pass, 2,000 feet above the sea, eastward to the mouth of the Tees, and southward to Scarborough and York.

Another characteristic rock of this glacier is the felsite from the Lake District.

The moraine on the south side of this glacier may be followed as it trends westward from near Whitby, keeping north of the Cleveland Hills (which were not imbedded in the ice), until it again turns southward on the west side of those hills, and passes through Oulston down to Osbaldwick and the city of York. It has throughout the typical form of a moraine, and is plentifully sprinkled with large blocks of Shap granite, Lake felsite, and also blocks from the Pennine Chain.

From the Cleveland Hills to York the moraine may properly be called *lateral*, and, like all lateral moraines in Switzerland, it gradually decreases in elevation above the sea, as it proceeds from the source to the end of the glacier. Thus this moraine shows the Stainmoor glacier to have been 600 feet thick at Northallerton, 500 feet at Thirsk, and 400 feet at Easingwold.

At this ratio it would have been only 300 feet thick at its termination at York, but other considerations indicate that its depth there was somewhat greater.

The terminal moraine forms a great arc across the vale of York, convex on the south side, and is covered with large erratics, some of which are now placed in the grounds of the Philosophical Society of that city.

Following the moraine westward to Allerton Park, we meet with a great *medial* moraine, running south-east and north-west, on the east side of which Shap granite and Lake District boulders are abundant; but on the west side of which both of these rocks utterly fail, and we find that we have entered upon a third glacier which, although flowing here side by side with the Stainmoor one, has its own characteristic features.

The boulders carried by this glacier are all from Wensleydale, or from the region south of it, and consist mainly of carboniferous limestone and sandstone.

The medial moraine, which divides what may be called the Wensleydale glacier from the Stainmoor glacier, is, like the medial moraine between the Kander and the Aar glaciers, and that between the Linth and the Reuss glaciers in Switzerland, in large part stratified, and consists of half-worn and partly angular gravel containing large boulders.

The west lateral moraine of the Wensleydale glacier crosses the railway between Nidd Bridge and Wormald Green stations, keeps approximately along the Permian outcrop, and is finely exhibited about Markington and from thence to Fountains Abbey.

One of the conical mounds of the moraine at Markington is supposed by archæologists to be a barrow, and has been tunnelled in the vain hope of finding treasure. A similar mistake has been made in America, where the hummocks of both kames and moraines have been held to be Indian mounds, and English geologists appear to have made the same error in the neighbourhood of Ilkley, where the moraine mounds are mapped as Roman forts.

North of Markington, at a place called Haddockstones, the moraine has reversed the course of a stream called Cayton Gill, which has been forced to leave its valley, turn at a right angle, and flow into the river Ure, instead of into the Nidd.

This is, as we have already seen, a common habit of moraines. The finest example in Switzerland of the reversal of drainage by a moraine is at the south side of Lake Thun, where the Kander River, which formerly flowed into the Lake, was compelled to take a backward and roundabout course. In 1711, however, the inhabitants, by an artificial cutting through the moraine, brought the river back to its original channel.

Between Markington and Fountains Abbey, the moraine is heaped up in great hummocks, inclosing small meres, and is covered by large boulders. At Fountains Abbey it is sharply defined, and nature and art have here combined to give it a more beautiful setting than any other moraine in Great Britain. Close to the abbey the graceful moraine hummocks rise and block up the valley.

Northward the moraine can be followed as it keeps along the western edge of the Permian outcrop, past Winksley and Kirkby Malzeard to Masham, where, as elsewhere in this area, it sharply divides the drift-covered from the driftless area. Here the moraine turns westward into Wensleydale, and may be traced step by step from Fearby Cross to Jervaulx Abbey and up the valley.

Between Jervaulx Abbey and the cliffs on the south side of the valley the moraine forms a series of terrace-like ridges parallel to the valley, precisely resembling the lateral moraines of Switzerland. Moraine terraces are indeed better shown here than at any other point in England with which I am acquainted.

We thus see that a glacier seventeen miles broad, diminishing in height from north to south, flowed down the vale of York as far as the city of York, and that this glacier was the result of the union of two ice-streams, whose line of junction is marked by a medial moraine.

Inside and north of the terminal moraine, the till is deep, the large erratics are abundant, the exposed rocks are striated, and there are all the indisputable marks of the passage of a glacier.

Outside and south of this moraine there is no drift but such as can be satisfactorily explained as the result of aqueous action and floating icebergs.

Following the outlines of the Wensleydale and Stainmoor glaciers, we find a lateral moraine on the north side of the Wensleydale glacier, running through Barden Moor, and the moraine on the south side of the Stainmoor glacier finely shown at Kirkby Ravensworth, between which place and Dalton it is headed against the mountains in typical ridges and hummocks, and is full of characteristic Shap granite boulders.

The north side of the Stainmoor glacier was confluent with other great glaciers coming from the north-west, which together made an ice-sheet covering all England and Scotland north of this district, except the very highest points.

Tracing the Stainmoor glacier westward, by means of its boulders and moraines, we find it increasing greatly in thickness until at the point where it branched off from the Irish Sea glacier it was about 2 000 feet thick.

Thus we find that a tongue of the Irish Sea glacier passed eastward across the Pennine Chain to the Cleveland Hills, where it divided into two branches, one of which went south to the city of York, which is built on its terminal moraine; while the other flowed out of the Tees and was deflected southward along the coast by the North Sea glacier, with which it became confluent.

I now come to the consideration of the most important glacier of England, which, flowing down from Scotland and reinforced by the glaciers of the Lake District and of the region about the Nine Standards on the one side, and by large glaciers coming from Ireland on the other, filled the bed of the Irish Sea as far south as Wales.

Like all other glaciers, this Irish Sea glacier is limited and defined by its lateral and terminal moraines, which can be followed continuously around it, step by step. Coming from many sources, it is a compound glacier, and has many medial moraines, each with its characteristic boulders. In general it may be said to be distinguished in England and Wales by the occurrence of certain granites from Criffel in Scotland and from Eskdale in the Lake District.

Its size, depth, and movements will become evident after a description of its moraine.

From the distribution of Shap granite and other rocks on the high ground about the Nine Standards, and from the direction of the striæ and the height to which the drift extends, we learn that glaciers descending from the mountains of this district, joined the great glacier descending from Scotland. The valley known as Ribblesdale is as good an example of a glacial bed as the Haslithal in Switzerland.

The lateral moraine of the Ribblesdale glacier may be followed high up the mountain on the east side of the valley to near Skipton, where it turns eastward to bound a tongue of ice which flowed across the low pass in the Pennine Chain. At the same time the rock striæ, which have been approximately north and south, here point eastward.

The moraine can be traced [illegible] Skipton on to Rumbles' Moor at an elevation of [illegible] south of Ilkley, where under various names, such as 'Laneshaw Delves,' 'Skirtful of Stones,' 'Long Ridging,' &c., it surmounts the tongue of ice on the moor and, bending southward, crosses the Aire at an elevation of 600 feet below Bingley.

The edge of the ice pushed over the cliff at Ilkley and heaped up the rocky moraine at the back of the town.

On the south side of the Aire the moraine can be followed continuously as it ascends the hill and bends again westward, crossing the Worth near Damems and Ingrow, north of Haworth, and again reaches the west side of the Pennine Chain south of Skipton.

The Aire glacier, as we may call this tongue of the main glacier, was characterised by an abundance of limestone boulders, brought out of Ribblesdale. In the moraine about Bingley these are sometimes 12 feet in diameter.

South of Skipton the great moraine can be traced from Ickornshaw Moor, in a nearly straight line, along the west flank of the Pennine Chain for fifty miles to Macclesfield and Congleton. It is heaped up in great mounds on the west side of Boulsworth and Black Hambleton, at an elevation of 1,200 feet, and from thence passes Worsthorn and east of Burnley to Bacup in Rossendale.

There we encounter the main stream coming from Scotland, and granites from the Criffel and Eskdale rocks appear in abundance.

North of Bacup the glacier came down the east side of Pendle Hill, and was charged mainly with local material. Pendle Hill was not entirely overridden by the glacier (which did not here rise higher than 1,000 feet), but divided it. Near Bacup, the main stream charged with Lake District and Scotch erratics, which had come down the western side of Pendle Hill, is reached. South of this point the moraine as a line of drift hummocks, often nearly a mile wide and 200 feet or more in depth, may be followed past New Hey, Grotton, east of Oldham, Staleybridge, and east of Stockport to the mountain-side east of Macclesfield. [illegible]hing Manchester a new and interesting ingredient is found in it, namely, chalk flints carried from the bed of the North Irish Sea. These chalk flints continue as an essential ingredient of the moraine throughout all the remainder of its course in England and Wales. They show that we have now reached the main Irish Sea glacier, which, unimpeded by intervening mountains, flowed from the south-west of Scotland into the Irish Sea, and, keeping west of the Cumberland mountains, advanced upon Lancashire by way of Morecambe Bay, and was not brought to a stop until it reached the escarpment of the Pennine Chain.

After a study of the shores of the Irish Sea and St. George's Channel, both in Great Britain and Ireland, I am convinced that *the flints came from the bed of the Irish Sea, and not from Ireland as has been supposed*, having seen indications that the bed of that sea is in reality a great eroded chalk basin. Small outliers of the chalk not yet eroded are still to be found at various points upon the shore in Scotland, Cornwall, and Ireland.

Having reached that portion of the glacier which advanced over the bottom of the Irish Sea, we should expect to find in its terminal moraine other substances besides flints indicative of that fact; and at Macclesfield and farther south we do actually meet with transported shell fragments.

These shell fragments, which are not found in the moraine except where the glacier can be proved to have advanced from the sea, have been the subject of much misunderstanding.

English geologists, almost to a man, have adopted the view that they prove a great marine submergence of 1,350 feet or more, and this view has unfortunately retarded the progress of geology to an immeasurable extent, both in England and on the continent of Europe.

The shell fragments in the moraine east of Macclesfield, on Moel Tryfaen in Wales, and at other points in the terminal moraine of the Irish Sea glacier, were simply—as all the facts lead me to believe—carried there along with Criffel granites in the glacier itself.

The power possessed by a glacier of raising stones to points higher than their source can be abundantly proved by facts observed in many parts of Great Britain,[1] Germany, Russia,[2] Switzerland, and America,[3] and therefore the height above the sea of these shell fragments constitutes no valid objection to this explanation.[4]

On the crest of Penobscot Knob, Luzerne County, Pennsylvania, at 2,088 feet (aneroid), I found a fine transported boulder of white Pottsville conglomerate, measuring 9 feet × 6 feet × 4½ feet. It rests upon an outcrop of Catskill sandstone hundreds of feet higher than any outcrop of the conglomerates round the Wyoming coal basin. It is about three miles distant from any possible source, and is in the direct line of the ice-motion.

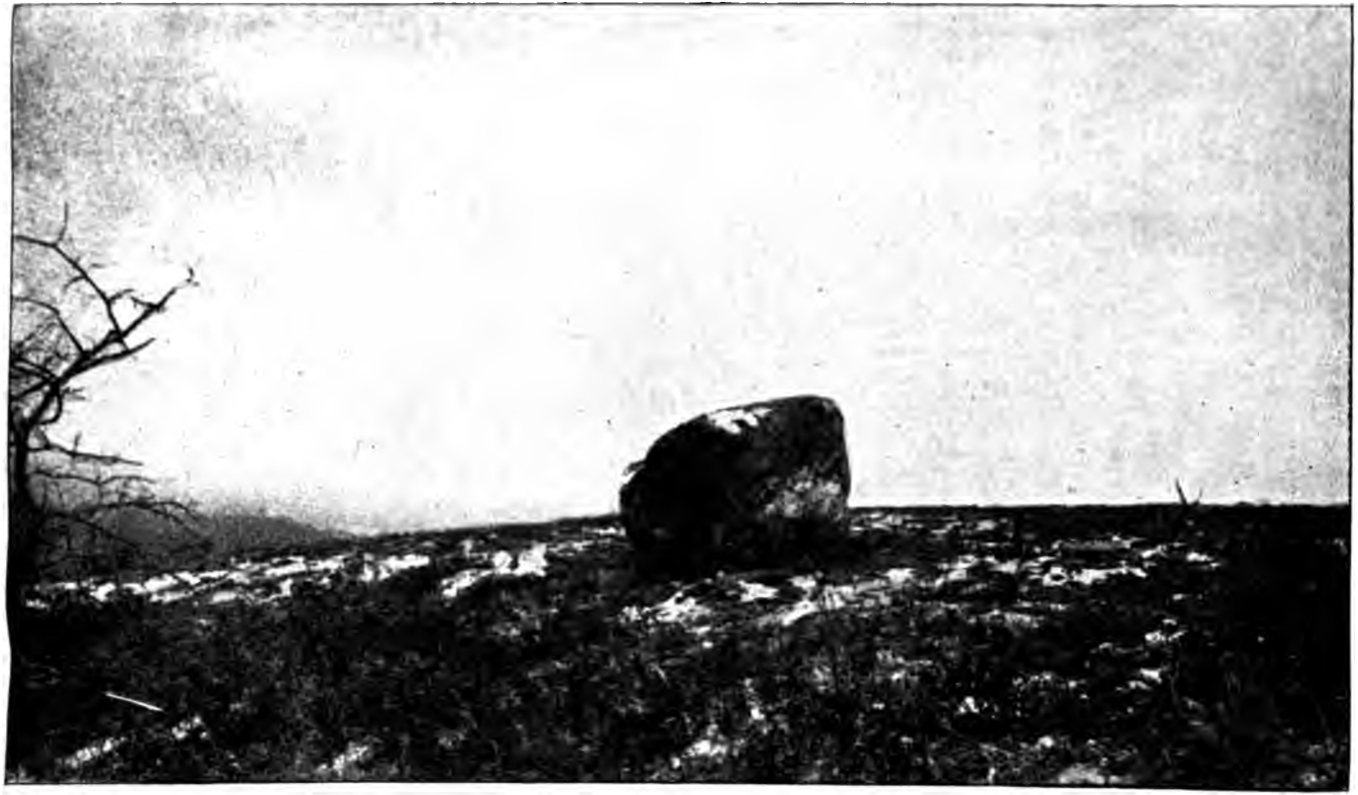
Continuing to trace the line of the terminal moraine, we find that it passes through Congleton to Madeley (where

---

[1] Darwin, *J. G. S.*, 1848. [2] Helmersen.

[3] Lewis, *Report of the Terminal Moraine of Pennsylvania.*

[4] See also Prof. J. F. Blake, on 'The Shell-Beds of Moel Tryfaen.' *Geol. Mag.* Decade III. Vol. x. No. 348, p. 267, June 1893.—J. F. L.



Boulder of Pottsville conglomerate on Penobscot Knob, Luzerne County, Pennsylvania.

the railway cuts through it), and thence southward on the east side of the Cheshire plain to Wellington. At Wellington, which is built on the morainic hills, North Welsh rocks appear in it; and we see that a glacier coming eastward from the Snowdon region has now joined the large glacier from the Cheshire plain.

The medial moraine caused by the entrance of the Welsh glacier is, in fact, beautifully exhibited at Ellesmere, where it is heaped up in a series of irregularly placed, and in part stratified, hummocks enclosing more than twenty-five meres. From Wellington the moraine curves round the north side of the Wrekin, which the glacier was unable to surmount, crosses the Severn near Buildwas, and goes through Burton west of Much Wenlock, and thence to Leebotwood in Shropshire, five miles south of Shrewsbury, this being the point of its farthest extension southward.

It now turns north along the foot of the Welsh mountains, but gradually rises higher upon them as it goes northward. It passes from a point west of Shrewsbury to a place called Mountain Lodge, west of Ruabon, and often assumes the character of a medial rather than a terminal moraine, as it divides the Arenig glacier from the northern glacier.

At Mountain Lodge it is seen at an elevation of 1,200 feet, and is very typically exhibited as a succession of drift ridges covered with boulders, among which are many of Eskdale granite, while shell fragments and chalk flints also occur.

The moraine is finely marked high up the east flanks of the Welsh mountains, and between Mountain Lodge and Minera rises up to 1,400 feet. Its medial character in certain places is shown by the occurrence of Arenig boulders on its west side, and of Eskdale boulders on its east side.

North Wales being a centre of glaciation, the terminal moraine of the Irish Sea glacier becomes now also the terminal moraine of Welsh glaciers, and continues therefore as a medial moraine all around North Wales. It can be traced to the top of the Halkin Mountain, and then westward along the north coast of Wales, past St. Asaph, Colwyn, Conway, and Penmaenmawr, to Bangor, where once more it turns southward, and keeping east of the Menai Strait, runs past Moel Tryfaen and along the west flank of the Snowdonian Mountains out to the farthest end of the Lleyn Peninsula at Aberdare Bay, where, containing boulders of Criffel granite, Lleyn rocks, and chalk flints, we may take leave of it as it enters the Irish Sea.

Wales had its own separate glaciers, each also defined by lateral and terminal moraines, and many of these I have also studied, and represented on the accompanying map. One at least of the Welsh glaciers, which we may call from its characteristic boulders the Arenig glacier, certainly joined the great Irish Sea glacier, and it is probable that the Llanberis glacier and others in Carnarvonshire did the same.

It can be shown that this Irish Sea glacier was about 200 miles long; and that its thickness gradually increased from south to north. The Welsh mountains divided it into two tongues, one of which, reinforced by the Arenig glacier, flowed up the Cheshire plain to Wellington and Shrewsbury; while the other, crossing over Anglesey in a south-westerly direction and reinforced by the Llanberis and other local glaciers, was directed back into the Irish Sea.

A portion of this great glacier reached the Irish coast south of Dublin in Co. Wicklow. Where it abutted against the Welsh mountains it was some 1,400 feet thick, but 100 miles farther north on the west coast of Cumberland it had at least double that thickness, being able to ride over and striate mountains of that height.

Like modern Alpine glaciers, it was not so thick at its edge as in the centre, being more than 2,300 feet thick at Stainmoor Pass, and less than 1,000 feet thick at Pendle Hill.

At Manchester, which is nearer the middle of the glacier, it was at least 1,400 feet thick, as is shown by the fact that it striated the summit of the hills at Bolton 1,380 feet high. The striæ about Manchester coincide with the direction of boulder transport in showing a motion towards the south-east.

A quaternary submergence of about 150 feet is indicated by certain fossiliferous marine clays in this region.[1] Of more than one advance of the glacier, so often assumed, I have as yet found no proof.

We have now followed almost continuously this great terminal moraine of the united glaciers of England, from the mouth of the Humber to the farthest extremity of Carnarvonshire, and find that it makes a very sinuous line, about 550 miles in length, across central England.

This line, which rises from sea-level to about 2,000 feet, cannot by any possibility be interpreted as a sea beach. From end to end it has the same typical contours, though composed of different rocks: whether it lies in a river valley, upon a plain, or upon a mountain slope, it has the same shape and features, and is identical with the moraines of modern glaciers in Switzerland. The great ice-sheet which it bounds is in reality an assemblage of confluent ice-lobes; and we have distinguished the more important of these glacier streams bounded by the moraine as respectively the North Sea glacier, the Irish Sea glacier, the Stainmoor glacier, the Wensleydale glacier, and the Aire glacier. In Wales we have mentioned only the Arenig and the Llanberis glaciers, but at least twenty others can be distinguished.

Except where it separates the Welsh glaciers from the North Sea glacier, the great moraine now first described everywhere marks the extreme limit of glaciation[2] in England, and is an important feature which might well hereafter be marked on the geological map of England.

---

[1] Geikie, *Great Ice Age*, p. 33; De Rance, *Quart. Journ. Geol. Soc.*, xxvi. p. 641.

[2] Namely, of *solid ice* action. - J. F. L.

(Professor Lewis illustrated this paper by a sketch map of the glaciation of England, which he described as an attempt to express graphically the conclusions deduced after a careful study in the field of the complicated glacial phenomena of England, uninfluenced by previous theories. This map is reproduced in this volume (Map III. p. 26). Another map (No. II.) found among his papers showing the connection according to his views of the glaciated area of England with the glacial areas of Scotland and Ireland is given at p. 7.)

III

ON SOME IMPORTANT EXTRA-MORAINIC LAKES IN CENTRAL ENGLAND, NORTH AMERICA, AND ELSEWHERE, DURING THE PERIOD OF MAXIMUM GLACIATION, AND ON THE ORIGIN OF EXTRA-MORAINIC BOULDER CLAY.[1]

In a former paper, an attempt was made to define the limits of the glaciers of England at the period of their greatest extension, as marked by their terminal moraines. It is now proposed to examine the regions outside of and bordering these moraines, to inquire into the necessary consequences of an extended glaciation, and particularly to draw attention to some great but temporary lakes which then covered large areas in England, America, and elsewhere.

These lakes so characteristic of all glaciated areas are due to several causes. Some few are due to an actual scooping out of the solid rock by a glacier, many to an irregular deposition of the drift by which former water-courses are obstructed; and others to the terminal moraine, or to the glacier itself.

It is this third class of lakes we shall here consider. They lie at or near the edge of a glacier, and may be called *morainic lakes.*

These morainic lakes may be divided into *inter-morainic lakes*, *moraine meres*, and *extra-morainic lakes*, according to their position—back of, in, or outside—the moraine.

---

[1] Read in Manchester in the Geological Section of the British Association for the Advancement of Science, September 2, 1887.

1. *Morainic lakes which lie at the back of the moraine*

In this case a glacier has thrown its terminal moraine like a dam across a valley; and after it has retreated a stream flowing down the valley has been dammed back by the moraine so as to form a lake.

Such lakes are frequently much elongated in one direction, taking the shape of the valley. Their size depends upon the shape of the valley and the height of the moraine dam. When several valleys unite at the back of the moraine, the lake may be irregular and branching; and if the moraine is compact, an outlet for the lake is often cut through the rock, and a post-glacial gorge is formed. These lakes are sometimes very deep, especially in cases where the valley has been due to a fault, and the glacier has cleared out all the loose rock and sediment which previously lay in it. To a certain extent the glacier may have deepened the valley. As types of this class we may take the well-known Italian lakes. These long, finger-like lakes are dammed up at their southern ends by the terminal moraines of glaciers which descended over their beds from the Alps. Many Swiss and Bavarian lakes are similarly formed, Lake Constance being the largest example. This lake is dammed on its north side by the great terminal moraine of the Rhine glacier, and owes its large size to the flatness of the region in which it lies. Its present outlet to the west by way of Schaffhausen, is a post-glacial one cut through rock. Before it was obstructed by the moraine the pre-glacial Rhine flowed northward into the Danube. In the Black Forest the Titi See, and in Wales Llyn Padarn at Llanberis, are examples of this class. We shall call these *inter-morainic lakes.*

2. *Moraine lakes which lie in the moraine*

All these have quite a different form and origin, being always small, more or less circular, and often without inlet or outlet. They lie in depressions in the moraine itself, and are filled by springs or by rain-water filtering into them; the natural hollows in which they lie are primarily due to the melting of masses of ice enclosed in the moraine, and are called kettle-holes in America. These kettle-holes are as characteristic of all moraines as are their counterparts, the conical hills or 'hummocks'; and both kettle-holes and hummocks are shown by their internal stratification to be original features of the moraine, and not to be due to subsequent erosion.

Kettle-holes may be either dry or filled with peat (as is most usual) or with water—in the latter case forming the ponds or small lakes under discussion. They are particularly abundant in medial moraines, which as a rule have a more hummocky character than terminal moraines.

These lakes seldom occur singly, but are generally crowded together irregularly and disconnectedly, and are often only a few yards in diameter.

As they are usually too small to be called lakes, and as the word pond is apt to imply artificial construction, I shall use the old English word *mere* already in many instances applied to them in England.

As examples we have the numerous meres which formerly existed in the moraine of the North Sea glacier at Holderness, and which are now artificially drained.

We have also the meres in the great medial moraine between the Arenig and the Irish Sea glaciers, at Ellesmere in Cheshire. At this picturesque locality most of the meres—over twenty-five in number—have received separate names all ending in 'mere.'

So abundant are meres in the great moraine of the Baltic glacier, the so-called Höhenzuge, which traverses Mecklenburg, Pomerania, and Prussia, that the region is called a 'Seenplatte.'[1]

In America also meres are scattered by the thousand among the moraine hummocks. In Wisconsin alone there are over 2,000 of them, many of them lying directly in the great moraines which traverse that State; and the terminal moraine of Pennsylvania encloses a number which I have described as sometimes lying 'above the level of the surrounding country, like the crater of a volcano.'[1] The moraines of the Swiss glaciers also enclose meres, as examples of which we may mention the Alnsoldigen See in the great medial moraine near Thun; and the numerous meres in the terminal moraine of the Rhine glacier about Ravensburg in Hohenzollern, which have been shown to alter in level according to the rainfall.[2] This class of lakes I shall designate as *Morainic Meres.*

---

[1] 'Report Z,' p. 20. Lewis, *On the Terminal Moraine of Pennsylvania.*

3. *Morainic lakes which lie outside the moraine*

When a glacier or a moraine obstructs a stream flowing from outside *towards* the glacier, a lake may be formed in the non-glaciated area bordering the moraine. Most of these lakes if dammed up by the ice-front are only temporary, disappearing with the retreat of the glacier; but if dammed up by a moraine they may be permanent. Even when the glacier itself forms the dam, the lakes, although temporary, may produce deposits of much geological importance because of the large size they may attain.

Inter-morainic lakes and moraine meres are practically independent of the size of the glacier; but in the class of lakes now described it is evident that the larger the glacier, the larger will be the lake that it makes; the broader the glacial front, the broader will be the lake, and the greater will be the number of streams obstructed, while the lake may be as deep as the glacier itself.

A small glacier may only dam back a single stream, but an advancing ice-sheet may block up the drainage of half a continent. Whenever a glacier advances against or across the drainage, it must form bordering lakes.

---

[1] 'Report Z,' p. 20. Lewis, *On the Terminal Moraine of Pennsylvania.*

[2] *Ibid.*

The most familiar modern example of a lake of this class is the Marjelen See, dammed back by the great Aletsch glacier, which goes athwart a side valley. Among other Swiss lakes thus formed may be mentioned the Mattmark See and a number of cases cited by Charpentier.

Of ancient examples of such lakes, which disappeared on the retreat of the glacier, hundreds of cases might be given in Switzerland. Wherever a small valley bordered the Rhone Valley, level stratified deposits of clay, gravel, and sand mark former temporary lakes dammed back by the ancient glacier. These deposits, which often contain scratched erratics dropped from icebergs detached from the glacier, may resemble genuine glacial till, and have been mistaken for it. Whole regions, however, and not merely single valleys were once covered by a lake of this extra-morainic character.

A great area in Northern Switzerland, south of the Jura, and east of the ancient Rhone glacier, seems to have been once a lake dammed up by the end of a glacier. Perhaps the most instructive example of such a temporary lake was due to the Rhone glacier, which in Hohenzollern advanced uphill and against the drainage. Its limits are defined by a typical terminal moraine, and north of this moraine is a deposit of boulder clay, containing the same erratics and extending over a wide area. Clearly, a lake was once formed by the damming back of the ice front. It is interesting to learn that this lake deposit is considered by the geologists of Switzerland and Germany as a ground moraine made by a glacier of the first epoch.

Dr. Fraas, for example, describes the moraine proper as made in the second glacial epoch, calling the stratified lake deposit the 'Grund' or 'Alt Moräne,' and the true terminal moraine the 'Schutt' or 'Fung Moräne.'

The same mistake, as we shall see, has been committed in North Germany, in England, and in America. Here it is that we approach the important point of this paper, viz. *that the so-called 'ground moraine of the first glacial epoch' is in reality a lake deposit.*

It will be evident that if, instead of dealing with local glaciers, we have to do with large ice-streams at all comparable to those which form the Greenland ice-sheet, or to those which can be shown to have formerly invaded northern Europe and north-eastern America, the lakes formed outside of the glacier may under certain circumstances attain dimensions which render them objects of high geological importance. We begin to see that the ideas of the early geologists about floods and *débâcles* are perhaps nearer the truth than our modern conceptions.

We shall call this third class of lakes formed outside of the glacier *extra-morainic lakes* or *extra-glacial lakes.* The latter term may be used when, as in the case of Lake Agassiz in America, the lake was made during the retreat of the ice, being not necessarily outside of its terminal moraine. While inter-morainic lakes are limited by the size of the moraine and of the valley, extra-morainic lakes are limited only by the size and depth of the ice-front. An ice-wall several hundred feet in height will dam back the waters to that height so long as a solid front of ice is maintained. But on the retreat of the ice, or when through melting a sub-glacial passage has been opened, the waters will find an outlet, and the lake will be more or less emptied, often suddenly. By the sudden emptying of extra-morainic lakes in Switzerland, destructive floods are often occasioned. The *temporary* character of these lakes is one of their distinctive features.

The three kinds of morainic lakes now described may be distinguished to a certain extent by *the character of their deposits.*

1. *Inter-morainic lakes,* made when streams flow outwards from the retreating glacier, form deposits partly brought by the advancing glacier, partly dropped by icebergs during the retreat of the glacier, and partly brought

down by the streams in post-glacial times. The gravel and silt due to the latter agency are very abundant, and are still being deposited. All the deposits consist of materials derived from within the glaciated area and are mainly fluviatile.

2. *Moraine meres*, formed in the glacier itself, contain only material carried by the glacier or its subglacial waters; and it is only when the moraine was formed in water that any admixture of the rocks from the unglaciated area is possible.

3. *Extra-morainic lakes* may contain a proportion of material from outside the glacier as great as that derived from the glacier itself. A fresh-water lake outside of the moraine would often be frozen over, and still more frequently be covered by floating ice driven about by the wind. Stones would be carried from all sides of the lake as well as from islands in it, and dropped from the ice-cakes over its bottom.

Icebergs detached from the ice-wall would contribute numerous glaciated stones, while ice-rafts from the bordering land would add material of a heterogeneous character. Great quantities of fine mud would be contributed by the glacier and would form a dense deposit at the bottom of the lake, while sands and gravels, brought both by the glacial streams and by rivers coming from without, would make a succession of stratified deposits. The only fossils possible in such a deposit would be fluviatile shells brought in by the rivers, and mammalian and other remains of land animals collected together during the draining of the land by the rising flood.

Any striated stones dropped into the dense mud from icebergs would be retained in a more perfect condition than those in the shifting, sandy, impure moraine. The mud would be most dense and freest from sand near the foot of the glacier, while at the farther shores of the lake it would necessarily be replaced by sands and gravels at the entrance of rivers, and by shingle, frost-broken stones, and other beach deposits along its edges.

From the temporary nature of the lake we should find the high-level deposit thin and sometimes quite eroded away, while frequently evidences of floods, *débâcles*, and sudden movements would occur. Should an iceberg ground in a shallow place, we might find occasional striæ on projecting rocks, especially if those rocks were made of limestone or other soft material.

Now these are precisely the phenomena which occur in areas once covered by extra-morainic lakes; and the deposits now described are those which have been so generally mistaken for the direct product of a moving glacier, and have been the cause of so much misunderstanding.

Reserving the name *till* for the unstratified, stony mass made directly by the glacier itself, we may use the term *boulder clay* for the clayey portions of the extra-morainic drift; and may now proceed to the examination of the more important areas covered by extra-morainic boulder clays and gravels.

Northern Asia, as has long been known, is covered by a drift deposit of enormous extent and great thickness, and large boulders are here and there scattered over the surface as if dropped by icebergs. Cotta and others have supposed that the region has been submerged beneath the sea, but the total absence of the remains of marine life in any of the deposits is a fatal objection to this view.

Marine shells abound in all northern waters however cold, and are found at the very foot of the glaciers in Greenland and in Spitzbergen. As the boulders came from the south as well as from the north, and as no genuine till, moraines, and other glacial phenomena occur, it was not a northern glacier that carried the drift.

The suggestion of Mr. Thomas Belt, in 1874, that an extension of the polar ice-cap had formed a barrier to the northward-flowing rivers of northern Asia, and had caused a great fresh-water lake, is the only plausible one as yet advanced, and it is supported by the fact that fresh-water shells (*Cyrena fluvialis*) and the remains of land animals have been found in portions of the drift. As the moraine of the northern ice has not been determined in this region, Mr. Belt's hypothesis, however, still remains without proof.

Even more interesting and instructive examples of great extra-morainic lakes occur in the United States and in British America.

The terminal moraine of the great ice-sheet has recently in that district been accurately followed for many thousand miles, and is often a prominent feature in the landscape.

At the last meeting of this Association I gave its general course across North America, and stated then what I have always hled and endeavoured to prove in Pennsylvania that it marked the extreme limit of glaciation. Professor Chamberlin, of the United States Survey, and other geologists have, however, spoken of this moraine as 'the terminal moraine of the second glacial epoch.' Their reason for this opinion has been that there are certain deposits outside of the moraine which they believe to have been made by an ice-sheet of the first glacial epoch. This 'first glacier,' like the supposed one in Switzerland, has left no polished or striated rock surfaces, and no moraines or kames, to prove its existence.

The drift outside of the terminal moraine I confess troubled me greatly in western Pennsylvania, where I called it 'the fringe,' and did not attempt to explain it. The facts in Pennsylvania regarding 'the fringe' are these[1]: Outside of the terminal moraine in the western third of the State, where the great glacier ascended from Lake Erie, is a narrow zone of country less than five miles in width, apparently non-glaciated, yet with great erratics brought from Canada and perched on the hills, and also with occasional thin deposits of clayey drift somewhat resembling glacial till. The hill-tops bearing these boulders show no signs of glacial erosion, being in all respects identical with those south of the limit of all drift.

---

[1] 'Report Z,' p. 201.

Professor Wright found the same phenomena in Ohio, where 'the fringe' is often much wider than in Pennsylvania, but yet very irregular and sometimes absent. The explorations of the Government geologists farther west have shown that what was a narrow zone in Pennsylvania widens out into a tract sixty or seventy miles west of the Missouri River.

In Dakota, for example, far outside of the moraine, there occur clusters of granitic boulders upon the hill-tops, often unaccompanied by till or gravel, the boulders having been transported from the Laurentian region, nearly five hundred miles away. The rock on which they rest is not striated or disturbed, and the boulders finally cease with no sign of a moraine bounding them. No trace of marine life has ever been found in any part of 'the fringe,' and there are many other considerations which preclude the possibility of its being due to any submergence beneath the sea, such as has been advocated by my distinguished friend Sir William Dawson. Nor is the supposition that this extra-morainic drift was made by a former extension of the ice supported by what we know of the action of glaciers elsewhere. It is inconceivable that the laws of glacial action, as we know them in modern glaciers, should be violated by the first glacier, while followed perfectly by the second.

On the other hand, I am not aware of a single fact which opposes the explanation that the boulders in extra-morainic regions were carried and dropped by floating icebergs detached from the ice-front.[1] And this explanation amounts to a certainty when we discover by reference to the maps that it is *only where streams flowed towards the moraine* that such extra-morainic deposits occur. Thus in eastern

---

[1] The 'ice-front,' Professor Lewis evidently means, abutting upon morainic lakes of all descriptions, and *not* upon the sea-shore. An 'ice-front' is so associated with glaciers entering the sea that it is necessary carefully to remember this whenever 'bergs' are alluded to in these papers. – H. W. C

Pennsylvania, where the streams flowed southward with the glacier, there is no 'fringe,' but in the western part of the State, where many streams flow northward or towards the moraine, the 'fringe' appears for the first time, and is only seen where the ice-front can be shown to have obstructed the drainage and formed an extra-morainic lake.

Great deposits of stratified clay in Ohio are, as Professor Newberry has shown, certainly due to deposition in an ancient lake. In Nebraska and Dakota the Missouri and its tributaries seem to have formerly flowed toward the ice-front, and to have been dammed up by it. Afterward, as in the cases of the Weichsel and the Elbe near Berlin, in North Germany, it seems to have found a passage southward along the front edge of the ice-sheet. An instructive example of an ancient lake dammed up by a glacier has been studied by Mr. Upham,[1] and described under the name of Lake Agassiz, which extended from Lake Winnipeg southward along the Red River Valley for some hundreds of miles.

The most important extra-morainic lake in North America, however, probably occupied that part of British America between the Missouri Coteau and the Rocky Mountains. This region has been excellently described by Dr. G. W. Dawson,[2] and the facts which he has given us are of high value, although it is impossible for me to accept his conclusions.

The Missouri Coteau, described by Dr. Dawson as 'the most remarkable monument of the glacial period in the western plains,' is a great line of drift hills which rises suddenly out of the western prairie, and is composed of innumerable tumultuous hillocks made of Laurentian boulders and gravel, including many kettle-holes and moraine meres without inlet or outlet. It is thirty miles wide, and with its continuation, the Coteau des Prairies and others, is more than 1,000 miles in length, being the most gigantic terminal moraine known in the world. Between this great moraine and the Laurentian mountains to the east the rock surfaces are striated parallel to the transport of erratics; there is a deep covering of till, and there is every proof that the Coteau is the terminal moraine of an enormous ice-sheet which moved westward and southward to that line.

---

[1] *Bull. Minn. Acad. Nat. Science*, II. p. 290, 1882.

[2] 'On Superfic. Geology of Central Region of North America,' *Quart. Journ. Geol. Soc.* 1875, p. 603.

West of the Coteau, however, the character of the drift suddenly changes. Glaciated rock surfaces are no longer to be seen, and a great level plain 450 miles wide, and more than twice as long, extends to the base of the Rocky Mountains. The drift in this great plain is only about half as thick as it is on the other side of the Coteau, and deposits of tough boulder clay containing scratched stones and beds of gravel are seen. This clay, or so-called till, which continues to the base of the Rocky Mountains, weathers into perpendicular columns, and often shows signs of bedding, being analogous to certain tough boulder clays in Norfolk and Lincolnshire. The boulders here are partly from the Laurentians to the east, and partly from the Rocky Mountains to the west. This so-called commingling of the drift is also a feature of certain parts of England south of the terminal moraine.

It is clear that we have here a typical example of an extra-morainic lake. The rivers all flow eastward towards the Coteau, so that the ice-front formed the eastern and the Rocky Mountains the western shore of this great but temporary lake. The Rocky Mountains are known to have supported small glaciers of their own, and icebergs from both east and west sailed over the lake, contributing their boulders. A great glacier lay east of the Coteau, and a great lake west of it at the period of maximum glaciation.

Dr. Dawson's idea that the Coteau was merely a shoal in an ocean, and that the whole region was depressed beneath the sea, is entirely unsupported by the facts which he has

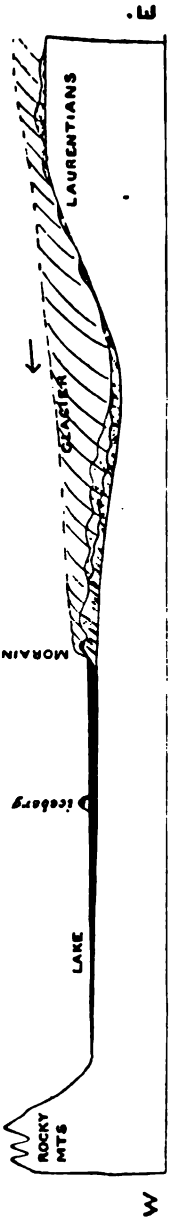


Fig. 6.—Large Extra-Morainic Lake in North America.

himself so carefully recorded; and is at variance with the purely glacial character of the deposits east of the Coteau and their purely fresh-water character west of it, and with the typically morainic features of the great Coteau itself.

The accompanying diagram will explain itself.

We now turn to the condition of England south of the terminal moraine during the glacial period.

It is well known that a great part of central England, including Lincolnshire, Norfolkshire, Suffolkshire, Cambridgeshire, Nottinghamshire, Staffordshire, Warwickshire, &c., is covered by a series of boulder clays and other drift deposits, which have long been a subject of investigation, and as to whose origin very diverse opinions are constantly expressed. One need only look through the *Journal of the Geological Society* or the *Geological Magazine* to see the confusion into which English quaternary geology has fallen through these puzzling deposits.

Two schools of geologists have arisen, one of which considers the boulder clays as the direct result, or ground moraine, of a land glacier or ice-cap, while the other school as positively affirms a submergence of some 2,000 feet beneath the sea as the only possible explanation. The task of attempting to gain a conception of the history of the glacial period in England by reference to literature is, as I know by sore experience, a hopeless one.

There are, it seems to me, fatal objections to both the theories heretofore advanced. In the first place, it would be a curious kind of glacier which could at once carry boulders from the south as well as from the north, from the west as well as from the east, mixing them all in one deposit; and which was able neither to make moraines, nor to striate rock surfaces, nor to smooth projecting crags, nor to make the rocky till such as occurs in the north of England, in Scotland, and in Switzerland.

In the second place, it would be a remarkable ocean which contained no trace of marine life; which made no sea sand, nor beaches, nor any continuous deposits of any kind; which was able to submerge mountains in one part of the country, but on low hills and in valleys a few miles away left no trace of its existence. Neither theory will explain all the facts, and we must seek a new one. Indeed, many excellent geologists have given up the attempt to explain the phenomena of the glacial epoch in England, regarding the whole subject as a puzzle, the key to which has not yet been found. I trust that I may not be thought over-confident if I state my belief that the *terminal moraine* will prove to be the key to all these problems. It is only when we know the precise limits of the real glaciers of England that we are in a position to understand the deposits made at the same time at their edges.

I ask you to picture the great North Sea glacier coming out of the Skager Rack and advancing to the north of the Humber, its terminal moraine being heaped up both north and south of that point. Let us suppose that the glacier was here 300 feet thick (certainly a moderate estimate), and that England was then depressed 100 feet lower than it is now, as indicated by certain marine beds around the coast. The Humber would then not be able to flow out to sea, the advancing ice forming a great wall across its mouth. The result of this glacial dam would necessarily be an inland fresh-water lake, which would gradually extend up the valleys of the Humber and its tributaries to what is now the 400 feet contour line. The mouth of the Wash and the drainage of Norfolk would be similarly obstructed by the North Sea glacier. Icebergs from the front of the glacier would float over this great lake, and ice-rafts detached from its inland shores would bring rocks from various points of the compass to be dropped into the dense mud forming at its bottom. On tracing the 400 feet contour line of the drainage area of the Humber and the Wash upon the map, we find that this lake would cover a large portion of the counties already mentioned, and would reach down to the hill north of London.[1]

It would have finger-like extensions reaching up all the tributary valleys of the Trent, the Dove, the Derwent, the Don, the Dearne, the Rother, the Calder, Aire and Wharfe, the Ouse, the Cam, and many others.

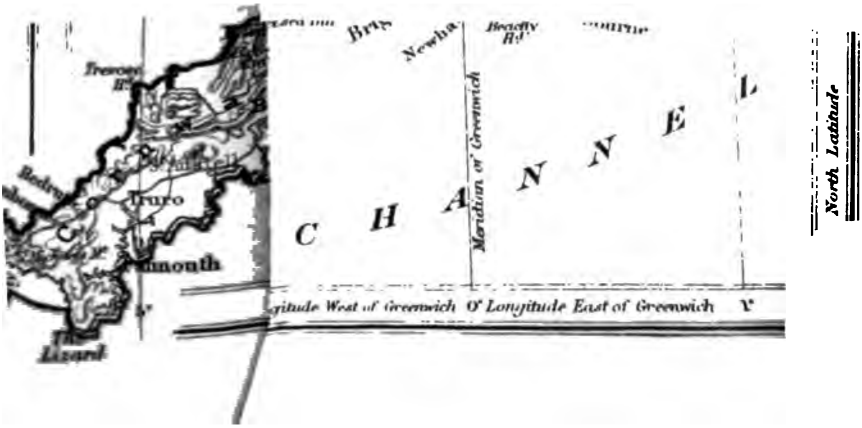
The Stainmoor glacier and the Wensleydale glacier would come down to this lake near York, preventing an outlet northward through the Vale of York; so that after attaining the 400 feet contour line, the only possible outlets would be across the low water-shed near Coventry and Birmingham to the Severn Valley, or possibly into the Thames drainage basin by way of Rugby and Oxford.

The chalk cliffs of the Lincolnshire Wolds would present an escarpment washed by the rising waters, and ice forming at its base would carry out great cakes of chalk. The deeply frozen chalk would crunch and crack and fall in large quantities into the rising flood, or be carried off by the ice-foot.

---

[1] Mr. Warren Upham, in his admirable sketch of Professor Carvill Lewis' life and work in *The American Geologist*, December 1888, p. 376, says: 'There can be little doubt that the continuation of Professor Carvill Lewis' study of the drift of England would soon have convinced him of the correctness of the opinions of Mr. Searles V. Wood, Junr., Mr. Skertchly, and Dr. James Geikie that land-ice during the earlier glacial epoch overspread all the area of the chalky boulder clay, extending south to the Thames.'

The above clear statement as to the true nature and origin of this deposit indicates that my husband could not at any time have reached the conclusion suggested by Mr. Upham.—J. F. Lewis.


Trevose Hd.
Truro
The Lizard
Newha
Beachy Hd.
C H A N N E L
Meridian of Greenwich
gitude West of Greenwich
0° Longitude East of Greenwich
North Latitude

Meanwhile vast quantities of mud would be contributed by the glacier, which would settle at the bottom in a dense, almost unstratified, deposit. Islands would appear in this great lake, Charnwood Forest being one of the most prominent of them; and boulders would be carried out from the islands on ice-cakes, which would be driven about in every direction by the winds. Finally, on reaching a depth of 400 feet, this great lake might burst its bounds, and rushing across the depression in the Lincolnshire Wolds at Louth, and across the depression in Central England by way of Leicester, Coventry, and Warwick, into the Vale of Evesham and the Severn Valley, would find an outlet into the Bristol Channel. This would be a genuine *débâcle*, a sudden torrent, uprooting trees, sweeping animals into the flood, and carrying along great masses of gravel and boulders towards the south-west.

In any case, as the waters rose they would overflow; and we should expect to find torrential gravels and other evidence of *débâcles* in valleys which could serve as temporary outlets.

As the ice began to melt and to retreat, the waters would find an outlet into the North Sea through or alongside of the ice, and the depth of the lake would be gradually lowered. The deepest and densest mud would be deposited nearest the glacier in the deepest portion of the lake; the deposits, on the other hand, at the inland borders of the lake would be thin and stony, and at the entrance of the rivers would be replaced by fluviatile sands and gravels.

The last deposits formed would be those washed in by the rivers, and would consist of purely local material of a sandy or gravelly nature.

After the entire withdrawal of the glacier, shoals and swamps and small lakes would long continue; and it would be found that many of the smaller streams had altered their courses through the filling up of their channels by mud.

The picture I have now drawn is, I believe, a real and not an imaginary one, and is sustained by all the facts I have been able to collect after careful studies in the field.

A clayey deposit, known as 'the great chalky boulder clay,' occupies precisely the position of the great lake just described, extending from the terminal moraine of the North Sea glacier, westward and southward up to about the 400 feet contour line, and it preserves all the characters of a typical lacustrine deposit, although held by some geologists to be a marine clay and by others to be a glacial till. It is entirely devoid of traces of animal life, and the only bodies of water known to be so constituted are lakes bordering a glacier.[1] The bones of mammals found in it and its associated gravels are of similar character to those found just outside the edges of all the ancient glaciers of Europe and America. The transported stones—in part from the North Sea glacier, in part from the glaciers of Stainmoor and Wensleydale, but mainly from the chalk escarpment and other inland cliffs and islands—are precisely such as we should expect to find in an extra-morainic lake having floating icebergs; and their commingling it is impossible to explain either by the glacial or the marine hypothesis. The clay is very deep at the east, but gradually thins out to the west, being replaced by gravels and by fragmentary frost-made detritus.

---

[1] It is necessary to note, however, that a bone of a whale is reported to have been found in the upper boulder clay. It is described by Mr. Plant in the *Report of the Erratic Block Committee of the British Association*, 1888. It was discovered at Newfound Pool, Leicester, associated with blocks of syenite from Groby or Markfield, about four miles distant, and was under about four feet of 'drift,' which Mr. Plant describes as 'Upper Boulder Clay.' This bone was 2 feet 6 inches long by 1 foot 8 inches wide. Nearly all the animal tissue had been taken out of the bone, owing to its lying so little beneath the surface in the sandy drift. No other bones or teeth of the whale were found. It has been placed in the Leicester Museum. Height above the sea, 210 feet. In reply to my inquiries, Mr. Plant informs me that there is no difference of opinion, so far as he is aware, '*about this bone being a bone of a whale.*' He also states that the 'upper boulder clay' (in which it was discovered) throughout the county contains large erratics; the lower boulder clay none larger than about 2 feet to 3 feet cube. If the bone in question was pushed out of the sea by a glacier, that glacier must have been far south of Professor Lewis' terminal moraine. Its height above the sea-level is not, however, greater than the depth of the submergence which he believed may possibly have taken place.—H. W. C.

If the height of the point above sea-level where this whalebone was found is *not* above that here assigned as the limit of submergence; and if the North Sea glacier not only carried boulders, sand, and shells lying in its path *upward*, toward the surface, as in the Swiss glaciers, but large bergs and blocks were also constantly breaking off from its front and floating inland on the surface of the great lake formed by the glacier-dammed rivers; the fact above stated does not seem to offer a valid objection to my husband's conclusion.

It is interesting to note that but *one bone* was found, not several or many, as would naturally be the case had the animal perished near the spot where the discovery was made.—J. F. L.

Stones from the island of Charnwood Forest have been wafted in every direction of the compass; and Shap granite boulders, brought down to York by the Stainmoor glacier, have been occasionally carried far back through the finger-like projections of the lake into the valleys of the Pennine Chain. The erratics at Sheffield,[1] Leeds,[2] Wakefield,[3] Halifax,[4] Nottingham,[5] Royston,[6] can all be most satisfactorily explained as having been carried in this manner by floating icebergs. They have been supposed to have been carried over the Pennine Chain by ancient glaciers; but as there is no trace of glaciation in these places, and as the Pennine Chain south of the Aire valley is free from all drift, the supposition is untenable.

Some geologists have held that the signs of glaciation have disappeared through atmospheric erosion. It is a fallacy which cannot be too strongly combated, that erosion is able to remove all drift from one area, while in an adjoining one it has not even altered the forms of moraines. The forces of atmospheric erosion are among the most uniform in nature, and we may be very sure that when a region is driftless now, it was driftless also in the glacial epoch.

---

[1] Green, *Geol. of North Derbyshire*, p. 131 (xlv. 30).

[2] Davis, *Geol. Mag.* pp. 79, 313 (xlii. 18).

[3] *Ibid.*

[4] *Ibid.*

[5] Green, p. 132 (xlv. 33).

[6] Reid, *Geol. of Craven*, p. 88.

While very thin at the above-named places, the clay becomes thicker and thicker as we go eastward.[1] At Cromer there are some very interesting aqueous and iceberg deposits, which point to the action of an oscillating 'ice-foot,' such as Dr. Kane has described as a perennial growth in certain Arctic harbours. The contorted clays at Cromer enclosing huge masses of chalk are quite unlike anything else I have seen in Europe, and indicate in a most interesting manner the conditions which prevailed about a rising lake just outside of the glacial ice-front. It is a mistake to call any portion of the deposit 'Cromer Till,' as there is no true till there. The passage of the so-called 'contorted drift' into 'chalky boulder clay' can be seen west of Cromer.[2] We may, I think, justly compare these deposits with the great banks of partially stratified tough clays which lie outside the submarine moraine of the Fredrikshaab glacier in Greenland,[3] or the similar deposits described by Nordenskjold and Hofer beyond the submarine moraines in Spitzbergen. Had these been made in fresh water the analogy would have been complete.

Of the many divisions that have been laboriously made of the various clays and gravels which compose the extra-morainic drift in the east of England it would be superfluous here to speak. Suffice it to say that they can all be explained as the products of an extra-morainic lake, some of them being made during its rise, some during its period of overflow, and some during its fall. It is interesting to find that at two or three isolated points the icebergs floating in this lake have produced slight striations on the rocks upon which they grounded. This is a very unusual phenomenon, although I have seen one case in the south of Ireland, and cases have been reported from Canada,[1] Denmark,[2] Russia,[3] North Germany.[4] Charnwood Forest has already been mentioned as an island in the lake, and on the granite on the north side of Mount Sorrel are marks closely resembling glacial striæ and held to be such by Mr. Harrison[5] and others. A careful examination has convinced me that this is not an example of true glacial striæ, but is a very local smoothing due to moving gravel, or possibly an iceberg, and Professor Bonney and Mr. Hill have come to the same conclusion.[6] The whole exposure is only two to three yards long, and the rest of the region shows no signs of glaciation. Another locality of striæ south of the terminal moraine has been reported from near Nottingham;[7] there, under a heavy bank of boulder clay, striæ were seen on limestone. The locality is now inaccessible, and is probably an instance of iceberg striæ. Mr. Hart writes to me of another instance in the soft oolite south of Lincoln. Some of these may be due to the post-glacial and gradual slipping downhill of a mass of boulder clay, coming under the designation of what I have called 'creep striæ' in Pennsylvania.[8] Another unexpected fact discovered during these investigations is that boulders are often much more finely preserved in *boulder clay* than in *till*:[9] the finest striæ being perfectly preserved on stones dropped from an iceberg into dense mud; while, on the other hand, in stony, sandy, heterogeneous till made by the glacier, the striæ are more or less rubbed away through the rough usage to which they have been subjected. Many instances, both in Ireland and England, might be given of this fact. It is curious to find that the most typical examples of glacier-scratched boulders are to be found where a glacier has never been.

---

[1] Green, *Geol. of North Derbyshire*, p. 133 (xlv. 34).

[2] H. B. Woodward, *Geol. of Country about Fakenham, Wilts, and Holt*, 1884, p. 19.

[3] Heim, *Handb. der Gletscherkunde*, p. 369.

---

[1] Logan, *Quart. Journ. Geol. Soc.*, 1872, p. 392. Lyell, *Travels in North America*, ii. p. 137.

[2] Forschhammer, *Bull. Soc. Geol. France*, 2nd section, iv. pp. 1177–84.

[3] Helmersen, *Mem. Acad. Soc.*, St. Petersburg, 7th section, xiv. p. 7.

[4] Heim, *Neues Jahrbuch*, 1870, p. 609; also Ramsay, *Quart. Journ. Geol. Soc.* 1862, p. 186.

[5] *Geol. of Leicestershire.*

[6] *Quart. Journ. Geol. Soc.*, 1878, p. 230.

[7] *Geol. of Leicestershire*; also *Quart. Journ. Geol. Soc.*, 1886, p. 460.

[8] 'Report Z,' pp. 96 and 35.

[9] Professor Lewis, it must be remembered, applies the name *till* to the unstratified stony mass made directly by the glacier itself; and uses the term boulder clay for the clayey portions of the extra-morainic drift.

One of the distinctions between boulder clay and till is that, in boulder clay the boulders often stand perpendicularly,[1] point upwards, while in till they lie horizontally, with their longest axis parallel to the ice-movement. In the first case they were dropped from icebergs, in the second case pushed along by the glacier.

To describe the overflow of the great lake just described into the Vale of Evesham and the Severn Valley—the latter of which received the drainage of the Irish Sea glacier which crossed the Severn at Buildwas, would too greatly extend the limits of this paper. This lake might perhaps be known as Lake Humber. It can be shown that the Stainmoor glacier, the Wensleydale glacier, the Aire glacier, and the great Irish Sea glacier were bounded by a large number of extra-morainic lakes, and that these temporary lakes only occurred where streams flowed *toward* the glacier. None of these can compare in size or importance with Lake Humber, and are recognised now only by very local deposits outside of the terminal moraine. These extra-morainic deposits were extremely puzzling to me when engaged in following the moraine, and were quite inexplicable until the main work was finished and plotted upon the map. I had noted them under the name of 'the fringe,' as in America, without understanding their significance. Now, however, in plotting the moraine upon a good map of England, and in noting those places where streams flowed toward the ancient ice-front, and where therefore we might expect to find extra-morainic lakes, it is interesting to find that just at such places 'the fringe' actually does occur, thus proving the precise accordance of fact and theory.

---

[1] A fact first pointed out by Mr. Mortimer, of Driffield.

A few of these extra-morainic lakes (which need not here be described in detail) may be mentioned:—

The Stainmoor glacier in the Vale of York dammed up several streams flowing westward from the Chalk Wolds, producing lakes of this character. So, too, the Wensleydale glacier dammed up the Nidd, producing an extra-morainic lake, which extended up Oak Beck as far as Harrogate, where there is a deposit of boulder clay with scratched stones. The Aire glacier was the cause of three extra-morainic lakes, one to the north-east, one to the south, and one to the south-west of the glacier. The first extended from near Skipton along the valley towards Bolton Abbey, and is recognised by deposits of tough boulder clay; the second was due to the damming up of Bradford Beck, and is well marked as far south as Bradford; and the third lay in the valley of the Worth between Damems and Haworth. Of these three, Lake Bradford seems to have been the largest. Finally, the Irish Sea glacier, while banked up at a high altitude against the west flank of the Pennine Chain, was the cause of a number of extra-morainic lakes in valleys whose streams flowed westward and toward the glacier. Thus we find extra-morainic boulder clay and erratics north of Bacup, east of Rochdale, east of Stockport, south and east of Congleton, and in the region about Wolverhampton south-east of the terminal moraine at Wellington. The Wolverhampton lake was an important one on account of the large number of Scotch boulders stranded upon the north side of the hills at Bushbury, and elsewhere near that town. The so-called 'terminal concentration' of Scotch erratics here has been described by Mr. W. Mackintosh[1] and others, and is regarded as an evidence of submergence beneath the sea, certain fragments of marine shells found with the boulders strengthening this conclusion.

---

[1] *Quart. Journ. Geol. Soc.*, 1879, p. 425.

But the shell fragments with the Criffel granite were evidently derived from the Irish Sea glacier, and were carried by icebergs to this, the first hill which opposed their southward drifting. The scattered erratics about Stafford, Stoke, and Longton, were carried in a long stream or lake which extended southward from the neighbourhood of Congleton, and seems to have joined the great Lake Humber in the Trent Valley. Thus it is that about Birmingham, for example, we find boulders belonging to the glaciers both of the east and the west of England. Icebergs from the North Sea, the Stainmoor and the Irish Sea glaciers have at this high point dropped their burdens, to form the curiously commingled deposits of that region—deposits otherwise inexplicable.

My friend Dr. Crosskey has considered that there are genuine glacial deposits about Birmingham, laying special stress upon a certain so-called till at a place named California. I have been unable to recognise this material as till, finding it to be simply the re-washed underlying permian marl, covered by the same torrential gravel that is so common in the Midland Counties.[1] A local clay similarly remade out of a mesozoic clay occurs at Rugby,[2] and is also of fluviatile origin. In no place in England outside of the terminal moraine have I found any proof of the presence of a glacier.

The supposed glacial striations which Dr. Crosskey has described on the trap of Rowley Regis are (so far as I could see) due either to plant roots or to ploughshares, being totally unlike true glacial striæ, but identical with similar superficial markings I have seen upon trap rocks in the non-glaciated part of America.[3]

---

[1] An account of Professor Lewis' re-examination of the California deposits has been given in the introductory chapter of this volume.

[2] Wilson, *Quart. Journ. Geol. Soc.*, 1870, p. 195.

[3] *Proceedings of the Birmingham Phil. Soc.* iii. p. 459. Although I admit the force of some of the objections urged against the glacial origin of the striations on the Rowley Regis rocks, I am yet not absolutely con-

The evidence against a great submergence of any part of England in quaternary times is equally strong; but in order to show that extra-morainic and fresh-water lakes and streams issuing from them and from the glaciers are the true causes of the drift deposits of central England, it will be necessary to examine here certain cases which have been adduced in proof of marine submergence.

There is little doubt, as shown by fossiliferous marine deposits, that during the glacial period a submergence of about 100 feet on the east coast and 150 feet on the west coast of England took place. A greater submergence occurred in the late pleiocene or pre-glacial quaternary era; but of any greater one in glacial or post-glacial times, as so generally affirmed, I am unable to find any evidence.

Glacial moraines in Wales, Scotland, and Ireland came down nearly to the sea-level, and show from their sharp and distinctive outlines that they have never been submerged.

Great areas in the centre and south of England are perfectly free from all drift, although only a few hundred feet above sea-level; and it is clear that there have been no deposits made upon them since the tertiary age.

The advocates of submergence bring forward many supposed proofs of its existence, among which the most important appear to be the following:—

1. The occurrence of marine shells at an elevation of 1,300 feet at Macclesfield in England, Moel Tryfaen in Wales, and Three-Rock Mountain near Dublin.

2. The occurrence of drift at the top of the Cotswold Hills at a height of 750 feet.

3. The occurrence of Welsh erratics on the top of Frankley Hill, near Bromsgrove, at an elevation of 800 feet.

---

vinced of their soundness. I have discovered, moreover, a clay resting upon them containing stones with what I cannot but regard as true ice markings; and there is a distribution of local erratics from Rowley Regis to a distance of at least eight miles.—H. W. C.

4. The occurrence of Scotch and Welsh erratics at Burton, west of Much Wenlock, at a height of 750 feet.

5. The occurrence of transported boulders at high points in the interior of the Pennine Chain, in North Derbyshire, and in the Weaver Hills.

6. The occurrence of drift on the top of the Yorkshire Wolds.

7. The occurrence of boulders and drift at an elevation of 450 feet, at Specton, on the Yorkshire coast.

The first of these points I have already answered in a paper read before this Association a year ago, in which I showed that Macclesfield, Moel Tryfaen, and Three-Rock Mountain each lay in the path of the Irish Sea glacier, which had carried the shell fragments to the points where they now lie. Remembering that by a submergence of 150 feet the Irish Sea at that time extended over a large part of the Lancashire and Cheshire plains, and that it washed the base of Moel Tryfaen and Three-Rock Mountain, Dublin and the district west of it being under water, it will be seen that the shells need only be transported a very short distance in the direction of the ice-movement to bring them to their present position.

After a personal examination of these three important localities, I am convinced that this is the correct explanation. High-level recent shells in Scotland and elsewhere can, as I have formerly shown, be similarly explained, and the principle enunciated that wherever in Great Britain or Ireland marine shells occur in glacial deposits at high levels, it can be proved—through striæ, the transport of erratics, and the position and character of the terminal moraine—that a glacier advanced on to the land from out of the sea.

As to the second fact, the occurrence of drift at a height of 750 feet on the Cotswold Hills, described by Professor Hull,[1] Mr. Lucy,[2] and others, and supposed to be a sea-beach, it turns out that the highest of these gravels is an old pre-glacial, perhaps early tertiary, deposit made chiefly of quartz pebbles, and that neither large boulders nor boulder clay occur except at a much lower elevation.[1] The highest deposit of boulders is at Mickleton Tunnel, at about 400 feet, where they seem to belong to an old river bed, which was perhaps one of the overflow passages between Lake Humber and the Severn Valley. The distribution of the boulders points clearly to such stream action.

---

[1] *Mem. Geol. Survey. Geol. of Country around Cheltenham.*

[2] 'Gravels of the Severn, Avon, and Evenlobe, and their extension over the Cotswold Hills,' by W. C. Lucy, F.G.S., *Proc. of Cotswold Naturalists' Field Club*, 1869.

The third locality on the top of Frankley Hill, where at 800 feet Welsh erratics have been described by Dr. Crosskey, is, if the description is correct, a most important one, since it lies twenty miles south-east of the terminal moraine, and is far above the limit of any extra-morainic lake. An examination of this locality under the kind guidance of Dr. Crosskey has led me to the conclusion that there are no Welsh erratics or other drift there, and that the supposed boulder clay is only a decomposed permian deposit.

Angular blocks of felsite certainly occur in abundance all over the hill, but these are neither rounded nor glaciated, and are, I believe, *in place*, there being a core of Cambrian sandstone, penetrated by eruptive felsites of probably Arenig age, in the centre of the hill surrounded by permian strata.

This would be a new locality for palæozoic rocks in central England, but the discovery, by Dr. Lapworth, of a similar area in the adjoining Lickey Hills makes such a supposition the more probable.[2]

The high-level drift at Burton (750 feet) is, in fact, the terminal moraine of the Irish Sea and Arenig glacier—as I have shown in a former paper.

The erratics on the Pennine Chain, in North Derbyshire, and elsewhere are, as already stated, due to the grounding at levels under 400 feet of icebergs which had been floating in Lake Humber, and were blown by east winds up these valleys.

---

[1] Lucy, *l. c.* p. 4.

[2] In the introductory chapter of this volume the grounds upon which Professor Lewis changed his opinion respecting the local origin of the high-level felsitic blocks on Frankley Hill have been stated. See p. lxiv.

The supposed drift on the Weaver Hills is in reality only a decomposed Bünter sandstone or millstone grit.

The drift which has been reported on top of the chalk Wolds of Yorkshire, and has been supposed to be due either to submergence or to glaciers, proves to be only a local wash, the supposed erratics being merely chalk flints.

Finally, the drift at 450 feet at Speeton is the terminal moraine of the North Sea glacier itself, and shows that here the ice-front was at least of that thickness.

Thus all the seven supposed proofs of submergence in England can be otherwise satisfactorily explained, and we find as yet nothing to controvert our conclusion that the glacial phenomena of this country can be attributed neither to a universal ice-cap nor to a great submergence, but to a number of distinct glaciers, bordered by temporary freshwater lakes.

All England, therefore, may be divided into three geological districts at the period of maximum glaciation; these being: (1) the Northern District covered by glaciers; (2) the Central District covered by lakes; and (3) the Southern District intersected by torrential rivers.

In conclusion, while thanking most heartily my brother geologists for their kind aid during these investigations, I must ask them to pardon my presumption in coming across the Atlantic to attempt a solution of problems so long and so carefully studied by the ablest English philosophers.

I can only say in the words of one of the most brilliant English writers[1] that while 'Politics, industry, and art are local, science and research know nothing of country, and have no limitations of tongue, race, or government.'

---

[1] F. Harrison, *The Nineteenth Century*, March 1883.

Postscript added to abstract printed in 'Geological Magazine,' November 1887, *p.* 516

Since the paper was read of which the above is an abstract, I have found traces of the existence of a very much older series of glaciers than those here described.

Since the period of these ancient glaciers, which in many places were more extensive than the modern ones, earth movements have occurred and erosion has removed almost all their deposits, and generally obliterated striæ, so that the region subject only to the older glaciation now resembles a non-glaciated area.

The glaciers and their bordering lakes described above should therefore be considered as belonging to the second or last glacial epoch.

IV

THE SUPPOSED THREEFOLD DIVISION OF THE DRIFT[1]

THE threefold division of the drift proposed by Professor Hull, and adopted by members of the Geological Survey, and so generally supposed to indicate two glacial periods with an intervening submergence, I believe to be due to the varying conditions of a single ice-sheet, which during its advance produced the *lower till*; during its subglacial melting deposited the *middle sands*; and during its final retreat dropped down the *upper till*. In fact, I am by no means convinced that the threefold division is in any way a constant feature of the drift, even in England. In this country, as elsewhere, I have been far more impressed by the ever-varying deposits of the ice age than by any uniformity in their relations. Even in Lancashire, where the threefold division was founded, the deposits are anything but constant in succession; and Mr. Binney, of Manchester, whose careful work is well known, makes quite a different division from that of Professor Hull. Mr. Binney[2] makes an Upper and Lower Sand, and a Middle Boulder Clay; while Professor Hull makes an Upper and Lower Boulder Clay, and a Middle Sand.

As Professor Hull's upper boulder clay is on the top of Mr. Binney's upper sand, and Mr. Binney's lower sand is below Professor Hull's lower boulder clay, it appears that by combining the series of the two observers, we get a fivefold division of the drift, and this fivefold division is, I believe, actually to be seen at more than one place.[1]

---

[1] This paper bears no date, and there is no record of its having been read.

[2] *Proc. Manchester Lit. and Phil. Soc.*

The alternating layers of stratified and unstratified drift are, I think, due simply to the deposition of material, sometimes by the ice-sheet itself, and at other times by the waters circulating in and under it.

My observations convince me that the glacial period, instead of being a complex series of glacial advances and retreats, and of aqueous submergences and re-elevations, accompanied by recurrent cold and warm periods, was in reality as simple as one of the preceding tertiary periods.

I believe the history of the epoch to have been briefly this: a gradual elevation took place (of *perhaps* 500 feet), followed by a slight general refrigeration (of perhaps 15°), so that as a consequence glaciers grew in the mountains, many of them joining to form confluent ice-streams which flowed in the direction of least resistance.

Before the ice-sheet reached its greatest extension, the land gradually sank, bringing back warmer conditions, and causing the ice, after it had attained its maximum, to melt, and to retreat back into the mountains or to disappear.

The depression of the land was some 400 feet below what it is now, and occurred, as it seems, rather before than after the greatest extension of the glaciers.

After Note, November 16, 1886.

I have now changed my opinion with regard to Dr. Hull's three divisions in the drift. The Lancashire drift below 150 feet is marine, and the upper and lower boulder clays are the same deposit.

Mr. Binney holds the upper and lower boulder clays of Dr. Hull to be identical, to be one deposit with sand occasionally interpolated in its midst. I cannot agree with the interpretation that Mr. De Rance gives. His successive elevations and depressions and alternations of climate are at variance with facts observed in the east of England, and in glaciated areas generally.

---

[1] Professor Hull's section (*Geol. of Bolton-le-Moors*) shows four divisions.

The clays and gravels of marine origin were made partly as the ice was advancing, partly as it was retreating, and when the sea (150 feet or more in depth) was washing against the ice-wall, and was covered by floating rafts of ice. The sea was not an Arctic one, as the shells show—*Turritella communis*, *Purpura lapillus*, *Cardium edule*, and *Tellina balthica* being the commonest.[1]

---

[1] For Professor Carvill Lewis' final opinion with regard to the glacial history of Lancashire, see p. 253.—J. F. L.

V

THE DIRECTION OF GLACIATION AS ASCERTAINED BY THE FORM OF THE STRIÆ[1]

THERE seems to be a curious disagreement between certain Scotch geologists and the Irish geologists, regarding the inferences deducible from the shape of glacial striæ as to the direction of glacial movement.

It is well known that when well-preserved striæ are examined, they will be found in many cases to be blunt and thick at one end, while tapering to a point at the other. The writer has noticed this character in striæ of all sizes; from those several yards in length, where the blunt end may be an inch or more in breadth, to the finest scratches where, in order to detect the difference between the two ends of the scratch it was necessary to use a microscope. Frequently curious striæ can be found whose shapes closely resemble those of the characters employed in the cuneiform inscriptions of Babylonia.

Certain Scotch geologists appear to regard the *blunt* end as the point of impact of the striating agent, and as therefore pointing to the direction *from* which the motion came. Thus, in the reports of the Boulder Committee of the Royal Society of Edinburgh we read 'That the striating agent first struck the rock from the north-west is made evident by the circumstance that most of the striæ are deeper and wider at their north-west than at their south-east ends. This change in the striæ can be accounted for by supposing that the striating agent, as it moved over the rock, acted with a lessening pressure, by having rebounded from the rock after its first impact.'[1]

---

[1] Read in the Geological Section of the British Association for the Advancement of Science; Aberdeen, September 11, 1885.

A number of instances are given in the same report of striæ which are deep and wide at the north-west end, and which taper to a point at the south-east end; a fact regarded as indicating a motion across the Hebrides from north-west to south-east.

In the seventh report (1881) of the same committee, certain ruts are described as 'deepest and widest at their north ends,' and as tapering 'to a point at their south ends.' A slightly different method of producing such striæ is here suggested. 'The graving tool (it is said), which may have been sharp enough to act deeply at first, becoming blunt as it was pressed upon the rock, had left a smaller and fainter striation as it passed along.'

Again, in the discussion carried on in the *Geological Magazine* concerning the glaciation of the Shetlands, Mr. Milne-Home remarks that, if the striæ were discovered with their broad ends pointing southward, it would conclusively prove that the glacial movement came from that direction.

The Irish geologists, on the other hand, interpret the shape of the striæ as indicating just the reverse movement, although they agree with the Scotch geologists referred to that the sharp tapering ends of the striæ point to the direction from which the motion came, and also that the blunt end was made last.

Thus in the memoirs of the Geological Survey (explanation to sheets 86, 87, 88, p. 55), Mr. Kinahan describes 'a furrow 5 yards long, an inch wide at its south-east end, and 5 inches at its north-west end, showing that the ice came from the south-east,' and Mr. Du Noyer speaks of 'well-defined striæ, which are most usually thin at the end pointing north-north-west, and blunt at the other, or that pointing to the south-south-east, from which peculiarity of form it would appear that the ice-bearing currents set in from the former point'; and he gives a number of examples to substantiate his belief.

---

[1] 'Fifth Report' (1879), pp. 18, 20; see also pp. 29, 58.

The Rev. M. H. Close (a very accurate observer) has informed the writer that he is entirely in accordance with the other Irish geologists on this point, having observed in a number of cases that the blunt end was the farthest end, i.e. the end last made.

It thus appears that the same glacial striæ are interpreted by one geologist as proving glaciation to have come from a direction exactly opposite to that which another geologist claims to be proved.

As the point at issue is certainly of importance, especially in cases where other indications of the direction of glacial movement, such as the transport of identifiable boulders, are wanting, perhaps the conclusions of an American geologist may not be without interest.

In Pennsylvania, through which the terminal moraine of the great ice-sheet of north-eastern America passes from east to west, separating the glaciated area to the north from the non-glaciated area to the south, and where there is no question, therefore, as to the general southward direction of ice-movement—a matter, moreover, as much confirmed by the uniformly southward transportation of boulders as by the shape of the *roches moutonnées*, cragging to the south, the writer had a number of opportunities, especially when the soil had been freshly removed, of observing the shapes of striæ; and in all cases where the striated surfaces were approximately horizontal, found the broad and deep ends of the striæ to the south, and the narrow tapering ends to the north.

Descriptions and sketches of several of these are given in a report on the terminal moraine in Pennsylvania and western New York.[1]

---

[1] 'Report of Progress Z,' *Second Geol. Survey of Pennsylvania*, by H. C. Lewis, pp. 33, 85, 86, 107, 275.

One of the most interesting of these striæ, as illustrating the probable mode of formation, occurs on 'Table Rock,' at the Delaware Water Gap.[1] This is a large flat surface of Clinton red shale, planed off and covered with nearly parallel striæ, bearing about south, 14° W. One of these striæ is not only blunt at its southern end, but, at a distance of less than an inch from this, is continued by another scratch making a slight angle with the first, as though the stone pushed along by the glacier had ground deeper as it advanced, until it either hopped out, or more probably turned over and began cutting on another edge (I).

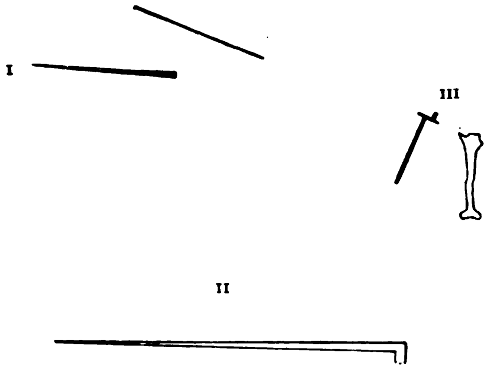


FIG. 7.—Glacial Striæ in Pennsylvania.

This turning over of the graving tool was often shown by the peculiar form of the farther end of a scratch, thus (II) and thus (III), the latter showing a rocking motion.

When the stone had been caught and ground into the rock, a deep irregular groove was produced at the farther end of the scratch, as was observed on a perpendicular cliff near the Kittatinny House, Delaware Water Gap.[2]

Some good wedge-shaped striæ were seen on the Lackawanna River, the blunt ends being to the south-west.[3]

In Pennsylvania such observations are not of much importance, since, as already remarked, there is no question as to the direction of glaciation; but in Ireland and Scotland, and especially in such outlying islands as the Hebrides and the Shetlands, they are of the highest importance, being often the only available means of interpreting the glaciation.

---

[1] 'Report Z,' p. 85.

[2] *L. c.* p. 275.

[3] Pp. 107 and 32, fig. 6.

During the past summer the writer had an opportunity of making some observations in Ireland, both at localities where there was no possible doubt as to the true direction of glacial movement, and also at localities where this direction was not previously known.

As examples falling under the former category, reference may be made to the small glaciers which descended from the 'corries' of the Dingle Mountains, Co. Kerry, a region not invaded by the great confluent ice-sheet which covered so much of northern Ireland. The paths and precise shapes of the Dingle glaciers are marked out both by their striated beds, with a glacial amphitheatre (a 'corry') at their head, and a semicircular terminal moraine heaped up at their feet. One of the most perfect examples of these occurs on Connor Hill, between Tralee and Dingle, at an altitude of about 1,100 feet.

Another excellent locality for determining the connection between the shape of striæ and the direction of glaciation is at Glengarriff, at the southern end of Ireland. Here – as shown by the striæ, the *roches moutonnées*, and the transport of boulders in the neighbourhood—there was a great ice-sheet flowing off to sea from the region of the Reeks as a centre. About Glengarriff the motion was to the south-south-east across the head of Bantry Bay.

Coming now to the central region of Ireland, which was overflowed by a great ice-sheet, we find in the region immediately south of the Shannon, about Limerick, a general southward movement. The writer has confirmed the observations of the Geological Survey, that pebbles of greenstone from the hills near Limerick, and even pebbles of porphyritic granite from the region north of Galway, have been carried southward and left on the northern slope of the Galty Mountains.

The striæ show the same movement. Thus, at St. Patrick's Well, close to Limerick, there are striæ on limestone pointing south, 36° E., with their broad ends to the south; and some large boulders have their longer axes lying in the same direction. Again, at Adare, the next village to the west, there is a finely glaciated boss of limestone where the striæ are remarkably striking, being black on a white ground, and the direction of glaciation is finely shown by their shape.

Finally, an instance may be given where the direction of glaciation was unknown, and was determined purely by the shape of the striæ. The writer found well-preserved glacial striæ covering flat surfaces of sandstone on the summit of the cliff facing the ocean at the Irish watering-place, Kilkee. The direction was north, 50° W., and south, 58° E. The question was whether the ice came on to the land from the Atlantic, or went off and out to sea. The shape of the striæ decided the point. The broad blunt ends were at their north-west or seaward ends, showing that the direction of movement was toward that point, and that the ice moved off from the land.

Taken in connection with the east and west striæ observed by Mr. Du Noyer at the mouth of the Shannon, and with other striæ observed by the writer south of that river, together with the evidence of transported boulders, we have proof of an ice-stream flowing westward along the valley of the Shannon out to sea.

In conclusion, there are certain precautions to be taken in making these observations which it will be well to mention. Every scratch is not blunt at one end, and there are many exceptions and reversals, as is to be expected under the circumstances of varying pressure, movement, and the size of the grooving stones.

FIELD NOTE-BOOKS

Professor Lewis was accustomed to bind together his Note-Books, and many volumes of them have thus been preserved.

These Note-Books contain the records of actual observations, which were generally written down upon the spot, together with many references to geological works, and many original remarks dealing with special and often very controverted questions.

They were not (as has already been stated in the Introduction) in any way prepared for publication, and were, indeed, subjected to no kind of revision whatever.

They show what he believed that he actually saw, and also what struck his mind most forcibly as requiring consideration, rather than indicate any finally accepted results of investigation. We find in them a vast mass of materials collected for the purpose of being thought about by himself, and *not in any sense a set of definite conclusions.*

The meaning of a section, as it appeared to him at a first visit, will be stated, but after a second visit another interpretation of it will sometimes be substituted. Frequently the words, 'I once thought, but now think,' will be found; not unseldom, however, no allusion to a change of opinion is made, as this was clearly unnecessary in notes intended for his own eye alone.

Professor Lewis' last journey to England, moreover, was made with the intention of again going over all the ground he had previously traversed, with the view of correcting any errors into which he might have fallen; and he held himself absolutely ready to abandon any and every theory he had formed should the discovery of new facts or a better understanding of old facts make such a demand.

Evidently, therefore, the publication of even the best selection that can be made from the Field Note-Books can do but scant justice either to Professor Lewis himself or to his researches. They contain, however, so many observations of value, the references to the literature of glacial geology are so abundant, the opinions expressed are so provocative of thought and so likely to promote a further examination of the districts as well as the subjects discussed, that it is felt it would be a greater act of injustice to withhold them altogether from the press.

A selection of extracts from the Field Notes has therefore been prepared. Professor Lewis' references to publications treating of glacial geology, together with his abstracts of some of the most important of them, have also been added. Not only is the literature of glacial geology remarkably copious, but so many valuable papers are hidden among the miscellaneous contents of the transactions of various philosophical and natural history societies, and so many have only been published locally, that it is often very difficult to discover them, and the most diligent student may be unaware of their existence. Professor Lewis' knowledge of this literature was so vast that it is believed a considerable service will be rendered to those who are pursuing the same branches of scientific inquiry by including his references and the accompanying abstracts of them with his Field Notes.

Many of these references and abstracts are embedded in the main body of the Note-Books, and were evidently in his mind when he was at work in the field. Others, however, are placed by themselves in isolated portions of the manuscript volumes, and he may or may not have been acquainted with them when he made his notes of the localities to which they refer.

No attempt has been made to arrange these various references and abstracts in one list, because the Field Notes, to be studied fairly, ought to be taken in connection with the information Professor Lewis actually had in his hands at the time at which they were written.

This selection, therefore, consists in the first place of extracts from the notes of those journeys from place to place which furnished the rough materials used by Professor Lewis in writing his papers, and give many details necessarily omitted from them, together with his own references to publications treating directly of the districts examined. These extracts are followed by a list of references drawn up by Professor Lewis, but not placed in position among his local notes.[1]

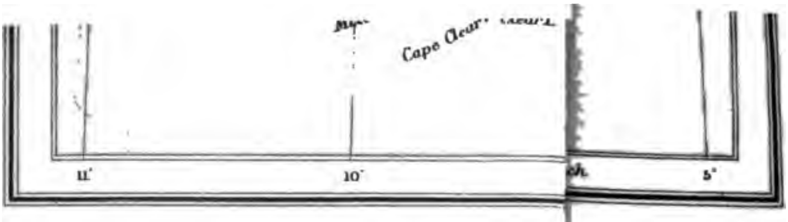
Some brief essays and memoranda are added, which have been found scattered through the volumes of Field Notes, and which throw light on the opinions he entertained, at least for the time being, on many difficult and complicated problems.

Guided by his leading purposes, rather than by any very definitely planned itinerary, Professor Lewis took very zigzag paths when working in the field; he frequently retraced his steps, and often approached the same district from different directions after a considerable interval of time. The country between Cork and Mallow, e.g., was traversed no less than six times. Suddenly, also, some point needing further investigation would strike him, and he would make a special journey for the purpose of determining it. It has proved impossible, therefore, notwithstanding every effort, to arrange his notes in any very satisfactory geographical order. A certain general arrangement of them has, however, been effected which, it is hoped, with the aid of the maps that are given, will show with sufficient clearness his most marked and important lines of route, together with their connection with each other and their relationship to the theories he advanced.

---

[1] Attention is here called to the fact that whenever throughout the following chapters of references and abstracts, Professor Carvill Lewis' *own personal observations*, or his running comments, or queries, following those of other geologists are given, they are enclosed in square brackets.

As the Field Notes have, so far as was possible, been arranged in order of time, the development of Professor Lewis' opinions with regard to British Glacial Geology may readily be traced from the day when he landed at Queenstown in June, 1885, to that on which his last observations were made in the autumn of 1887.—J. F. L.


Cape Clear
11°
10°
ch
5°

IRELAND

1. First Visit, 1885

The Glaciation of Ireland and its bearing on American Glaciation

[One of the chief difficulties of American geologists has een to find a satisfactory explanation for the southern ovement of the vast ice-sheet of North-East America.

No system of combined local glaciers is satisfactory, nce on elevated points the striæ are continuous.

The depth of the glacier was variable, being thin at the ges and thicker in the interior.[1]

Professor J. D. Dana suggested a greater elevation of e Laurentian highlands.

Sir William Dawson showed this to be inadequate. ofessor Hitchcock thought Labrador the radiant point.

Mr. McGee believed that the ice grew on its edges, and ve various reasons in support of this view.

Sir William Dawson considered this impossible, and erefore held to the old idea of sea and icebergs.

The writer, among others, suggested a chain of mountains around Hudson Bay. Greenland is thought by many to be the starting point, and the writer at one time also held this opinion. (See Upham, Wright, Croll, and Chamberlin.)

---

[1] In July 1882, Professor Carvill Lewis discovered well-marked striæ on the summit of Overlook Mountain, in the Catskill range, New York, at an elevation of 3,100 feet above tide; and transported boulders have been found on the summit of Mount Washington, New Hampshire, at the height of 5,000 feet. 'The extreme edge of the ice in certain valleys in Pennsylvania was about 700 feet thick . . . and five miles back from its edge it was at least 1,000 feet thick.' (*See* 'Report Z,' p. 14.)—J. F. L.

In order to gain light, I decided to study the glaciation of a country which on a small scale would present analogous features. Scotland has central mountains, Scandinavia has the same.

England, as the lower part of Scotland, was invaded by the Scotch ice-sheet, but Ireland has no central mountains.]

Queenstown

[On the hill above the town, whence a charming view of the harbour is obtained, is a quarry of green and yellowish-grey sandy shales of subcarboniferous age, corresponding probably to the Mauch Chunk red shale (xi) of Pennsylvania. These are broken, slickensided, and good for road beds, the lamination being *viscous* as it were. Most of the rock is sandy, almost a sandstone, not unlike parts of the Pocono sandstone. No drift or glaciation was noticed.]

Glengarriff

[The rocks are beautifully glaciated everywhere along the head of Bantry Bay, the striæ running out to sea at the water's edge. Striæ run south-south-east and south-south-west approximately, going southward. There are finely polished 'tors.' Typical till is well exposed north-west of Glengarriff on the road to Kenmare. At the base of the mountain, striæ run down steep surfaces pointing S. 35° E. In the till are many striated pebbles.

On one of the Caha mountains many fine striæ were found. I climbed up to see them. The striæ as we ascended were going south and south-east.

S. 25° E., S. 34° E., S. 36° E., S. 28° E. On the top, striæ at another locality were S. 35° E., the same as at the base of the mountain. Striæ run across the head of Bantry Bay. The strata all have a cleavage which dips steeply south-west, and the striæ here go along the strike.

I climbed up the side of the mountain from the schoolhouse, and went down by the road.

Near the top I found a pebble of white millstone grit.

On the road at the foot of the mountain near the schoolhouse, striæ are 90 S. 33° E. up a surface sloping 45° to north-north-west. Striæ go uphill at an angle of 45° about one mile south-east of Roche's Hotel. On the road from Glengarriff to Bantry is one of the finest glaciated surfaces that I have ever seen. The slaty rock with vertical cleavage is rounded and polished into a beautiful roche moutonnée 'tor,' on which the striæ ascend on one side and descend on the other. The striæ vary in width from two inches or more, down to the finest lines, and are beautifully preserved. They are often 10 feet in length. They run, S. 6° E., S. 7° E., S. 5. E. good, and the broad blunt ends of the striæ are to the south, viz. north to south. This is some 150 feet above the sea.

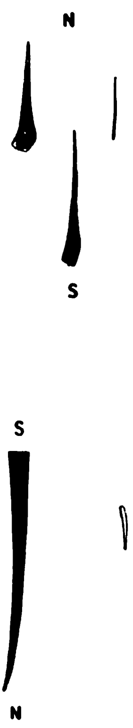


FIG. 8.—Tracing to show Direction of Movement up a Surface to the south near Glengarriff.

The rock slopes greatly upward where the striæ are finest.

According to explanation of sheets 192, 199,[1] the glacial striæ, generally throughout the region run north-west and south-east, whatever the slope or elevation of the ground, being generally more approximately north and south than east and west.

A number of tracings were taken by rubbing stove polish on soft paper. These all show the direction of striation by the shape of the striæ, blunt at the forward end (north to south). This is just as it was in Penna. They run across the head of Bantry Bay, as already observed by Close and others. (*Jour. Roy. Geol. Soc.*, Ireland, I. 1866–7, p. 227).

---

[1] This refers to the maps of the Geological Survey.—J. F. L.

The north and south direction here, however, is local, and conforms to the direction of the Glengarriff part of the bay.]

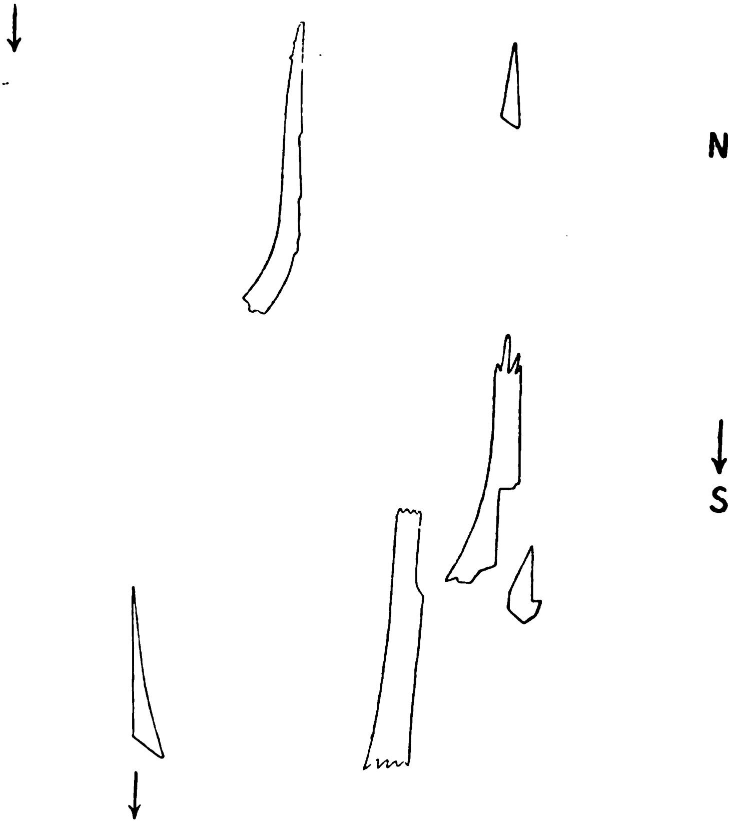


FIG. 9.—Glacial Striæ near Glengarriff.

Drive from Glengarriff to Kenmare

[The elevation of striæ noted on the Caha Mountains was 750 feet on the road, and 825 feet ± on top of the mountain.

Farther on, on top of the tunnel at 1,150 feet, striæ run S. 15° W.

Beyond the tunnel, at 1,000 feet, striæ are 90° east and west, going west.

Just beyond at 700 feet striæ are S. 75° west.

There is deep till near here.

Just beyond Talloha P. O. striæ are north-east and south-west, at 200 feet, on a well-smoothed sloping surface.

Five and a half miles north-west of Kenmare, on the road to Killarney, are good striæ going from north to south-east at 500 feet at the base of the mountains.

The south-west direction is said to be used by the inhabitants as a compass

N. 35° E.

Striæ 35° E. at the top of the pass.

900 feet±. Windy Gap.

There is a limestone boulder, 2,000 tons, at Roughty, two miles south-east of Kenmare (vide *Explanation of Sheet*, 184, p. 36). This boulder, called 'Cloghvorra,' 26 feet × 16 feet × 15 feet, of limestone lies on old red sandstone, 260 feet above the sea, on the side of a hill half a mile south of Roughty Bridge, having been moved southward.

A good description of the moraine at the north end of the Gap of Dunloe is given in *Ex. Sheet*, 173, p. 23.

Local glaciers here and on the Dingle promontory were more numerous on the north than on the south side of the ranges, the conditions of wind, moisture, and temperature being there more favourable.]

Killarney

[At the north end of the Gap of Dunloe are striæ S. 40° W. and N. 40° E. on the flat 'top' of red sandstone.

There is also a fine lateral and terminal moraine (?) of a local glacier going northward through the gap, one mile outside of it (?). Where cut by the road it is true till filled with glaciated fragments.

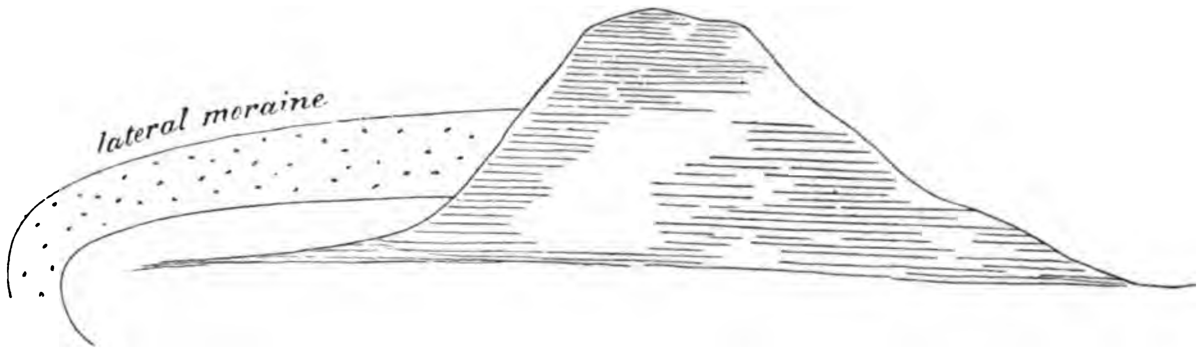


Fig. 10.—Lateral Moraine of Glacier at the Gap of Dunloe.

The direction of striæ north or south is undeterminable, owing to their being weathered.

Striæ are abundant along the sides of the gap, going with it.

At the highest point in the gap striæ run over a horizontal surface S. 40° W. Direction undeterminable.

A little farther south they run S. 60° W., still high up in the gap, the ice curving round, into the valley.

High up on the flank of the Bull, striæ run S. 75 W., at an elevation of 1,000 feet.

These striæ point up the Black Valley, swerving around the peak of the mountain.

Returning, I believe the moraine to be that of a northward-going local glacier.

It is an admirable example of a moraine, as fine, I suppose, as any in Colorado. There is a perfect semicircle of drift, highest nearest the mountain.

A section cut through it by the road showed the stones to be glaciated, and to have come from the pass. No limestone was seen, but conglomerate from the north end of Dunloe Pass was abundant.]

Dingle Promontory

[About four and a half miles west of Tralee, in front of the gap from which Tralee gets its water supply, the gorge heading in a fine amphitheatre, is the beautiful terminal moraine of a local glacier which went north.

There is another fine example of a local north-going glacier at Curraheen. This Curraheen glen moraine and a similar moraine at the head of Derrymore glen are described in the Explanation of Sheets, 160, 161, 171, 172, *Geol. Survey*, Ireland, p. 49. It is also figured on sheet 161.

On Dingle Bay two miles east of Dingle is a similar moraine of a local south-going glacier.]

Dingle

[I drove to Sybil Point and around Clogher Head to Dunmore Head.

No evidences of glaciation were seen. The rocks at Ferriter's Cave, Sybil Point, and Clogher Head, are sharp and devoid of glaciation. There are steep cliffs and jagged rocks of old red sandstone, or Dingle rock, at Sybil Point; eruptive felstones and greenstones (1,000 feet) at Clogher Head, and Silurian limestones at Ferriter's Cave; but all are sharp, none are drifted one on to the other, and the conglomerate ('inch' conglomerate) rocks south of Smerwick Harbour are also devoid of glaciation.

No glaciated pebbles were seen in this part of the promontory or at Dingle.

Wooden arrows (?) occur in the peat in the Valley of Slaughter and in the north-east of Dingle; they are very ancient, made of yew, and are found only here.

I drove from Dingle to Fermoyle, over the high pass of Connor Hill; road 1,400 feet high; magnificent scenery of the sea and mountains.

No signs of glaciation were found on the south side of the pass, but on the north side, at Pedlar's Lake, 1,100 feet, there is the finest example of an extinct local glacier that I have ever seen. It is on Connor Hill.

At the base of a grand glacial amphitheatre (corry) there is a glacial lake, ploughed out of the rock. Beyond this are fine glaciated striated surfaces of red sandstone, and far below is a semi-circular moraine, enclosing a good morainic lake.

The boundary between the glaciated and the unglaciated rocks can be determined within a yard or two, thus fixing the exact limits of the old glacier. The glaciation is very fine going north. The rocks are well rounded, polished, and grooved all along the path of the glacier, making thus a strong contrast with the unglaciated surrounding area.

This locality is typical for a local glacier, and is probably not exceeded anywhere. It is described by Mr. Close ('Some Corries and their Rock Basins in Kerry.' *Roy. Geol. Soc.*, Ireland, 1870, vol. ii.).

The moraine is high and made of sharp fragments

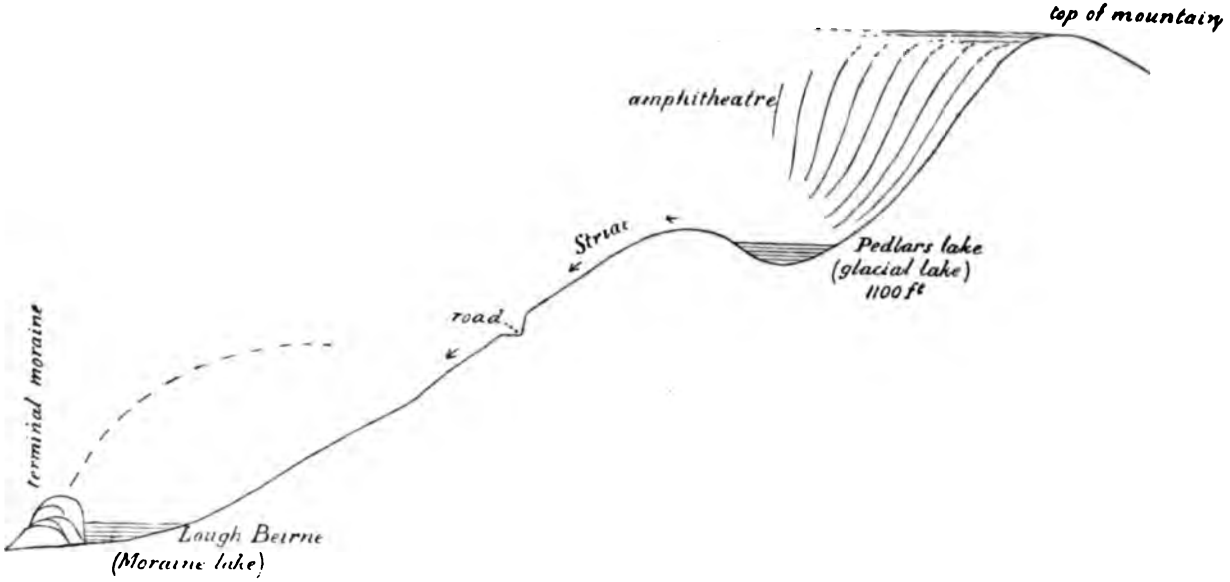


FIG. 11.—Extinct Glacier, north side of Connor Hill, Dingle.

mostly, often of very large ones. The lateral moraine is much higher than the terminal one.

I made some important observations here upon the direction of glacial movement. I found that on upward slopes or on flat surfaces the striæ as a rule are blunt at the end to which they go; but that on downward slopes the reverse is generally the case; i.e., they are sharp at the end towards which the ice moved. This I observed as follows:—

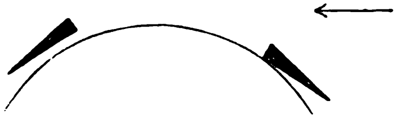


FIG. 12.—Shape of Striæ on Roches Moutonnées.

This is an important rule in determining direction. It is not good for every scratch, but for the generality of scratches. I observed it on a number of slopes, both up and down. Often on a downward slope the scratch is pointed at both ends and deepest in the middle. A little consideration of the conditions will show the above rule to be the natural one. A stone going uphill will be ground in deeper until it suddenly jumps out or turns over; while in going down a sloping surface the scratch thins out and disappears as the pressure becomes gradually less and the stone leaves it. I refer to rounded 'roches moutonnées' surfaces (fig. 13).

Another point observed was that while striæ are nearly parallel on up and horizontal surfaces, they vary much more on a downward slope. They vary most of all on a transverse slope, going downhill or alongside of a surface. On the same surface cross striæ, making with each other angles of 40°, were observed on a downward oblique surface. This is another point in determining direction.

The glacier here wends north and W.N.W. Most of these local glaciers go northward. At the present day the north-west winds are the wet winds. The winds were the same in the time of the local glaciers. The marks are so

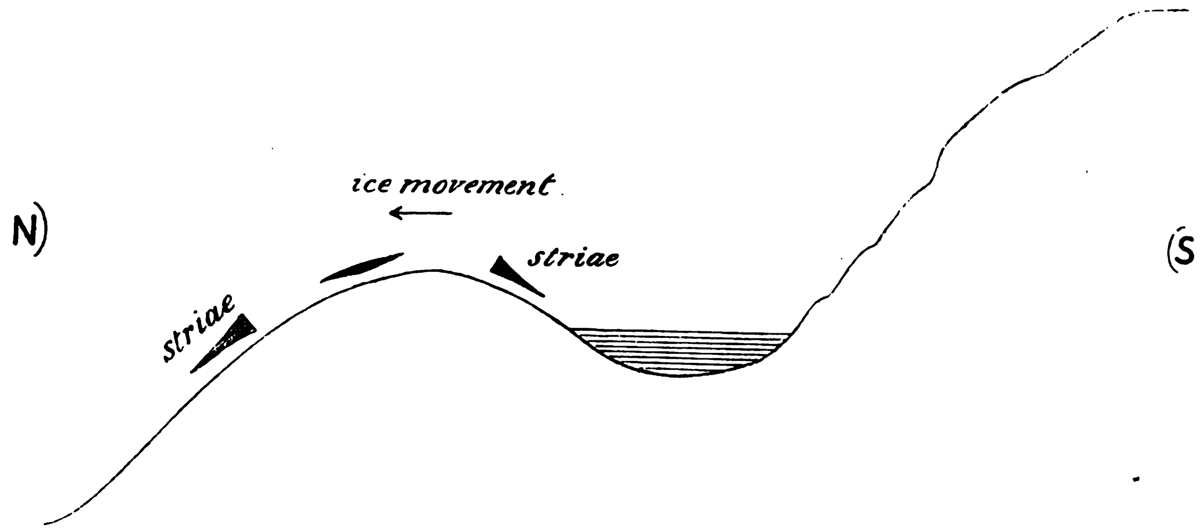


FIG. 13.—Direction of Ice Motion, as shown by Striæ on Connor Hill, Dingle.

fresh that they may not be over 5,000 years old. The following is an exact tracing of a scratch on a level surface.

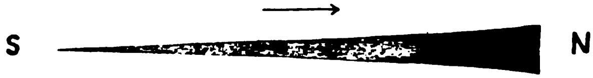


FIG. 14.—Glacial Scratch on Connor Hill, Dingle.

At Fermoyle, near the national school, is another glaciated surface. On flat surfaces the blunt end is plainly toward the sea, or north-east (N. 35° E., N. 40° E.) arguing another local glacier. The statement made by Mr. Du Noyer (Explanatory sheet, 160, 161, 171, 172, p. 48), that, 'On close examination we find that these striations are different in form from those of mountain glens, being thin at the end pointing seaward, and blunt in the other direction, thus suggesting that their formation is due to the sudden grounding of drift ice driven on the shore by winds and currents,' can only apply to some downward sloping surfaces, since the reverse is the case higher up on flat surfaces. Clearly here is another local north-going glacier.

Another large and fine terminal moraine of a north-going glacier is crossed by the main road from Tralee to Dingle, at Kilmore Lodge.

This glacier evidently came from Lough Adoon and down the ravine of the Scoria River.

The moraine is semicircular and large, forming hummocks, rising 75 feet or more. The road cuts into the moraine, showing it to be made of till, not, however, so compact or so rounded as the till of the general glaciation. Or could this be the moraine of a larger ice-sheet?]

Valentia

[I could not confirm the observation that there are striæ on the rocks north of Glanleam. Although the rocks were smoothed off by the sea, no undoubted ice-marks were seen. Nor were any striæ observed on the prolongation of Clokam, north of the inscribed Ogham stone and ancient cemetery, marked cromlech, at an elevation of 600 feet.

On the south shore along the road were many striated fragments of sandstone, but none were over 300 feet above the sea.]

Waterville

[Huge ridges of till are seen here. A section of a ridge of till crosses the road and seems to be genuine; the till contains scratched boulders of red sandstone, grey sandstone, shales, &c. It also contains some water-made sandy layers. It seems to be a great moraine. Another till ridge covered by boulders is on the south-east side of the lake. Lake Currane appears to be a moraine lake, separated from the sea by a narrow ridge of till. The mountains about here are all glaciated, according to Close and Du Noyer.

Fine sections of till occur on the sea beach. Two ridges are cut off by the sea, and the ends expose sections 100 feet high.

Many striated fragments are in them. Huge boulders, washed out, strew the beach. Some of these measure 10 feet × 8 feet × 5 feet or more.

Magnificent sections of till are seen nearly half a mile long.

A bed of stratified ' Champlain ' clay lies below the till.

In the till are stratified beds greatly contorted. I collected glaciated pebbles from this moraine. All the boulders on the beach where washed by the sea have their striæ obliterated.

The conclusion is that at the time when this moraine was made the sea was farther out than now, and the land was elevated, and that the sea has not come in over all Ireland.

The moraine is about a mile wide. It is finely developed in characteristic hummocks, on the road going north-east on the north side of the Cummeragh River. Boulders are piled up here.

A drive up the valley of the Cummeragh to its head showed the whole valley to be filled with drift.

The drift extends up to 500 feet. It indicates a huge glacier, three to four miles broad, twenty miles long, and over 500 feet deep, going from the Reeks to the sea at Waterville, where its moraine is seen.

No glaciation was noticed on the ridge of red sandstone north of Lake Currane.

On the road from Waterville to Derrynane, near Waterville, moraine heaps are finely shown, boulders are large and numerous, often 10 feet long, and a good section of the moraine is exposed along the roadside by Finneglas Stream. True till is seen here, in typical mounds and ridges. From the hill above is a good view of the flat tongue of drift below, at the head of Ballinskelligs Bay.

No signs of glaciation were found on the rocks to the south of this point. The red sandstone was glaciated, showing the Currane glacier to have been local.

On reaching an elevation of 666 feet in the pass, striæ were seen going N. 12° W.; and they occurred up to 700 feet. This was the overflow of the huge Kenmare River glacier.

On the south side of the pass there is till at 600 feet.

The Kenmare glacier was 700 feet thick where it emptied into the sea.

This great glacier had no moraine on land. Its moraine is out at sea. Scariff Island, made of drift, is in all probability a portion of its moraine.

Above Derrynane Bay are striæ at 550 feet, going N. 70° W. (on a sloping face of rock and not exact).

At Derrynane Abbey at the sea-level striæ are N. 65° W. The rocks are finely glaciated, rounded and grooved.

We have now seen three types of glacier.

1. A local corry glacier as on Connor Hill, Dingle, forming a glacier lake and moraine lake. A mountain glacier of which the beginning and the end could be seen at one glance.

2. A great valley glacier, terminating in a grand

moraine at the sea-level. The Ballinskelligs glacier. Lake Currane is a fine moraine lake on a large scale. There is a fine section of the moraine on the sea-coast, &c.

3. The Kenmare glacier, which headed in an ice-sheet and emptied into the ocean. Its moraine is out at sea, and the ice was 700 feet deep where it entered the water. It was probably 2,000 ± feet deep at Kenmare.

4. The ice-sheet of North America.

Returning over the mountain to Waterville I see, at 705 feet, striæ N. 50° W., and the rocks are glaciated up to at least 750 feet, if not to 800 feet. The glacier was therefore 800 feet thick. There are striæ also at the highest point of the road, 700 feet.

It looks as if the Kenmare and the Ballinskelligs glaciers joined, or almost joined, nearer their source.]

Waterville to Killarney

[At an elevation of 1,000 feet on the west side of the gap, called Ballaghisheen (leading from the valley of the Inny to Killarney), are striæ going west. Striæ again are observed going S. 20° W. at 150 feet on the east side of the gap.

Lough Acoose is dammed up by a moraine going north and south.

Farther on, the road crosses enormous masses of sharp rocky drift massed up against the north side of the mountains. These large masses of drift cover the base of the northern slopes of the Macgillicuddy Reeks, and appear to be a great mountain moraine. They continue almost up to the Gap of Dunloe, where is the circular moraine already described.]

Killarney to Mallow

[Soon after leaving Killarney the railway cuts through a great heap of drift, nearly 100 feet high.

Mounds and ridges, sprinkled with boulders, and resembling a moraine, occur, stretching for some miles along the railway, and appearing on both sides of it.

These would seem to have been left by a glacier coming down the Killarney lakes. There is an immense mass of drift material here, including many large blocks of sandstone. The underlying rock is carboniferous limestone.[1]

Just beyond Headford Station are more exposures of drift. Then follows a flat rolling plain, without sharp ridges or mounds, where boulders are not so large or numerous, and the drift is not so deep. Rock often now comes to the surface, forming ridges, and farther on, the railway cuts through rock with only a very little drift upon it. The rock here is Dingle shale.

At Rathmore no drift is seen. Broken rock here comes to the surface. No boulders are in the fields. There are mountains only two miles or so south of the railway, but there is no trace of drift about Millstreet.

We are clearly out of the glaciated area of the Reeks. There are no more stone walls dividing the fields at Millstreet.

No drift, except gravel, is seen at Kanturk Station, nor at Lombardstown nor Mallow. At the latter place rock comes to the surface at the station, but there is no drift upon it, the rock being broken and decomposed as in non-glaciated regions.

North of Mallow limestone appears, and here also there is no drift.]

Mallow to Limerick Junction by rail, and Tipperary to Cork

[I drove from Limerick Junction to Tipperary, at which place was a fine kame, running north-east to south-west. It was some 150 feet high, heaped up in a series of knolls to form a ridge, which terminated in the town. At openings made near the graveyard and where there was a cutting for a street, it was seen to be made of stratified sandy rolled drift, identical with the material of the Pennsylvania kames. The sand and gravel showed flow and plunge structure, and no large boulders or glaciated pebbles were seen.

---

[1] This is the terminal moraine of the Reeks glaciation. A mass of drift crossed by the railway between Killarney and Tralee is clearly part of the same moraine.

Another kame, parallel with this one, perhaps part of the same system of kames, ran to the east of the town. This showed Tipperary to be in a glaciated district, and perhaps near the terminal moraine.

The country is a flat limestone valley, and the Galty Mountains rise to the south of the town. I must visit these. Boulders of Galway porphyritic granite are said to occur upon them. (Wynne, Explanation of sheet 165. *Geol. Survey*, Ireland. Referred to by Kinahan, *Journ. Geol. Soc.*, Ireland, i. p. 204, who thinks they were brought by icebergs. Vide also Exp. sheet 164, p. 20.)

Returning from Limerick Junction to Cork I notice rounded hills, apparently of drift, a few miles south-west of the junction.

At Knocklong, just east of the station, a ruined castle stands on a lenticular hill of drift (?), known as 'Knocklong Hill' (vide Murray's *Handbook of Ireland*, p. 256). This place should be examined to see if it is *till*. The Galty Mountains rise to the east.

Waterworn pebbles were noticed at Kilmallock, but no large boulders. Waterworn gravel, with occasional large waterworn boulders, was seen just north of Charleville.

South of Charleville are rounded hills of till (?), resembling in shape the terminal moraine, the hills covering an area of two miles or so in width; and south of these hills the railway, for the first time since leaving Limerick Junction, cuts through rock. Buttevant-and-Doneraile Station is below, in the non-glaciated area. There are many rock cuttings, but no trace of drift along the railway from Mallow to near Blarney.

A large mass of stratified drift is seen on the east side of the railway, a quarter of a mile south of Rathduff, at 450 feet.

At Blarney there is drift resembling till, exposed at the station, and some drift in the fields; not much rock appears between here and Cork, and it is apparently without drift. In the environs of Cork drift is seen on the rocks (north of the Gaddig manure works).]

Cork

[Glaciated surfaces of rock occur here. Fine examples of glaciated limestone surfaces, collected near Cork, are placed in the museum of Queen's College. A hill of drift, mostly waterworn, occurs near the north end of the tunnel of the South-Western Railway. Till is seen in many places about Cork, but most of it is waterworn. The elevation is less than 200 feet above the sea.

Yet just above (north of) the bridge, over a creek north of Cork, along the railway to Mallow, red shales come to the surface with no drift on top, so far as could be seen from the railway. On the other hand, sandy drift was observed south of Mallow. What is this Cork drift? Is it true till? Can it be a marine deposit?]

Buttevant

[I drove from Mallow, through Buttevant, northward, across a country in which there were no signs of glaciation. Carboniferous slates near Mallow came to the surface with not a single pebble upon them, and limestone farther north did the same. Many openings and quarries showed that the soil over the limestone was made by its decomposition, and contained sharp fragments.[1]

The walls separating the fields were made of sharp fragments picked up in the fields. There was a complete absence of all drift from Buttevant to near the village of Fern. Here rounded boulders appeared in the fields

---

[1] On the maps of the Geol. Survey the term 'drift' is used to include the clay resulting from the decomposition of the limestone, and almost all limestone areas are therefore dotted. Misleading.

(as seen by the walls), at first sparingly, then abundantly, and, finally, heaps of drift were seen crossing from east to west. The drift formed low hills with hummocky contours, very characteristic, which rose out of the wide limestone plain, and were noticed as typical drift hills a mile away. The drift in them has been resorted by water, and is not true till. There are signs of stratification, and sandy layers, and the boulders are rounded. Most of the pebbles (1 inch to 1 foot generally in size) are of limestone, but red sandstone and other materials also appear as pebbles. This appears to be the extreme front of the terminal moraine. Drift of various kinds abounds farther north, but between here and Mallow the country is driftless. This point is near Fern, some six miles north of Buttevant and three miles south of Charleville.

A perusal of the memoirs of the Geological Survey relating to the region west of Cork renders it highly probable that the Cork drift is part of the Reeks glaciation.[1]

The drift appears to be limited to the valleys here (?). At Cork it is at 100 feet. There is none north of here on the hills. It appears again at Blarney at 300 feet above the sea. Four to five miles north of Blarney, at 430 feet, is a hill of stratified drift, well waterworn, and filled with rounded pebbles.

Adjoining this are rocks outcropping, with no drift on top. Are these old river-courses which were the waste weirs of the melting glaciers of the Reeks? It is a puzzle as yet.

I now believe these hills of stratified drift to represent great streams of water descending from the melting ice to the sea, by way of Cork, Youghal, &c. Had I time to follow these old water-courses I could learn whether they came from the Reeks glaciation or from the ice-cap.]

(A subsequent visit to Cork caused Professor Lewis to modify these opinions.)

---

[1] Not so.

Mallow to Waterford

[Good railway cuttings at Mallow show an entire absence of drift. The elevation is 250 feet. No drift is seen at Castletownroche, Ballyhooly, Fermoy, &c. Many outcrops of limestone occur with decomposed soil in place on top. Sharp limestone fragments are in the fields.

At Cloudulane in the railway cutting are clay (?) and pebbles (?), but sharp rocks covered only by their own débris occur beyond, and the walls are made of sharp stones. There is no drift of consequence in the Blackwater River as noticed at Ballyduff, &c.

At Tallow Road there seems to be some drift, numerous rounded stones appearing. Yet rock is seen beyond.

Hills of drift and rounded stones in the walls are found at Lismore. It appears to be the moraine.

Immediately east of Lismore the railway cuts through a series of rounded hills of coarse drift, clearly the terminal moraine.[1]

The gravel is rounded in great part, but not altogether. It is like the moraine of the western United States, rather than the unstratified moraine of the mountain region of Pennsylvania. The elevation here is only 50 feet above the sea. East of here drift abounds. Some of it is clayey, like till. Boulders are numerous, generally the size of cobblestones, sometimes larger. The drift is sandy and more or less stratified until after passing Dungarvan, and reaching the higher ground near the railway station. Large erratic blocks and true till occur about here. It looks as if there were local glaciers in the mountains immediately west. The rocks also seem to be glaciated. Beyond here (about Kilmeadan, &c.) are hills of clayey till, with slate (lower silurian) below. Erratic boulders of conglomerate lie on the silurian slates.]

In Explanation to sheets 167, &c. *Geol. Survey*, p. 16, an erratic boulder, two and a half miles north-west of Stradbally, is described as the largest in Ireland. It measures 50 feet × 35 feet × 18 feet, is 148 feet above the sea, and is of old red conglomerate resting on porphyritic felstone, having been moved at least two and a half miles from the nearest old red sandstone *in situ.*

---

[1] Of a local glacier descending from the Knockmealdown Mountains.

Waterford

This is a glaciated district. There are striæ on the rocks.

Extracts from Explanations, *Geol. Survey*, 167, 168, 178, 179, p. 16.

Drift derived from the lower silurian and old red sandstone rocks, 'the pebbles being imbedded in hard brown clay,' occurs along the coast from Tramore to Stradbally. Pebbles of limestone occur in the drift on the western slopes of the Commeragh Mountains up to 650 feet.

P. 80. On the Commeragh Mountains, near Rathgormuck, in the glen between Lough Cormgorra and Lough Covengh, are heaps of drift, and striæ at 2,000 feet, beautifully shown, going north-west and south-east.

Striæ east of Covengh Mountain go NN.W. and SS.E. Also north and south on the eastern side of Curraghmore demesne.

Drift of limestone, sandstone, &c., extends up the slopes of the Knockmealdown Mountains to fully 750 feet above the sea. South of Ballyporeen on the mountain, at 629 feet, are well-rounded pebbles of limestone in the drift. Then follows a fine description of this limestone drift lapping up on the mountain to the height of 750 feet. The boundary of it can be defined with accuracy. It sweeps along the north face of the mountain, and finally crosses it at 750 feet, &c., 'thus leaving the summit of Knocknageragh (910 feet) clear, and rising like an island out of the surrounding drift.' Other peaks of 900 feet also rise out of the drift.

No. 165. In the northern portion (p. 8), the drift is local [i.e. none at all]. In the limestone and old red mixed drift at the north-west corner of the sheet (i.e. east of Charleville) are many pebbles of syenitic and trap rocks. A gravel pit is near Carrigen cross-roads south-west of Kilfinnane (p. 23). The northern limit of limestone drift is on the north side of the Galty Mountains. No true drift is found on the south side of the Galtys or Ballyhourac Hills.

Nos. 188 and 189, p. 20.—The drift in this district is chiefly represented by large deposits between Youghal and Ardmore Bay, and in Castlemartyr Valley. Drift lies to the north of Dungourney by the road to the east of Clonmult. The beach at Whiting Bay shows syenite, trap, chalk flint, and all kinds of stones.

Waterford to Caher

[Large hills of till with numerous and large boulders are seen between Carrick-on-Suir and Kilsheelan. There is much stratified drift west of the latter place. Some of it is heaped up in a ridge, probably a kame. West of Clonmel is much drift; some stratified, some not. No till was observed about Caher and Clogheen.]

Caher to Lismore

[I drove across the Knockmealdown Mountains to Lismore. Immense piles of talus, sharp material, lie on the northern slope of the mountain, where the road makes a long bend. Immediately after crossing the top of the pass true drift is seen in great quantity. Many pebbles of limestone flint[1] were collected at 1,100 feet.

At 1,000 feet an excellent glaciated pebble was picked out of the till, embedded in clay. Till very deep, 40 feet or more, is often exposed in cuttings made by rivulets. All the upper part of the till, 10 to 20 feet, is somewhat weathered, and the scratches on stones are obliterated.

---

[1] Fossils, cyathophyllum corals, encrinite stems, &c. occur in this flint. It is of local origin, as limestone occurs on the top of the mountain.

On the south side of the mountain, on the road from the gap toward Lismore, immense masses of till are seen. Is it the terminal moraine? Many rounded pebbles are in it. The striæ are worn off by the weather. But deeper down, very freshly exposed, striated fragments are found. There is no evidence of water action here. It is true glaciation.

The pass is at least 1,200 feet high, and the ice came through it. The mountain to the east is 2,600 feet high.

No signs of glaciation are seen south of the mountain.

The glacial drift here noted is due to a local glacier. The material is all local.]

Cappoquin to Tallow

[Between Cappoquin and Lismore is a heap of till on the north side of the Blackwater, and large heaps of stratified drift lie on the south side of the river. West of here no drift is seen. Tallow Hill is covered by its own detritus of red sandstone. This detritus is often 10 feet deep, and resembles till. Some of the sandstone fragments are rounded and somewhat scratched, and all are embedded in a clay-like mass, which might easily be mistaken for drift, but the region shows no signs of glaciation. There are no signs of glaciation about Tallow, or on the River Bride, except at a point about one mile from its junction with the Blackwater. At Coolbagam, in the parish of Glandish, Youghal township, are gravel, rounded stones, sand, a sand quarry, and flint with encrinite stems. The locality is at a fork of roads south of Lismore 650 feet high; i.e. of the roads going to Killeena Barracks and to Youghal, being on the mountain road between Tallow and Killeena Barracks. This is on top of a hill (400 to 500 feet ± ?).

The occurrence of limestone with fossils shows it to be true drift.[1]

---

[1] But is not this a high-level marine gravel, just such as occurs all over the south of England? It is not true till.

On lower ground farther east drift is very scarce, only a few boulders indicating its presence.

It looks very much as if this region corresponded to the fringe in Pennsylvania. The rocks show no glaciation, but till and transported pebbles occur on high ground, both here and in Pennsylvania. In the valleys stratified drift appears, as also in Pennsylvania.]

Youghal

[Just west of Youghal is a great ridge of stratified clay, overlaid by stratified sand and waterworn stones, which makes a sharp bluff on the sea-shore, at least 60 feet high.

The beach is flat on either side of this bluff. I found chalk flints in it.]

See A. B. WYNNE, On Disturbance of the Level of the Land near Youghal. *Quart. Jour. Geol. Soc.*, xxiv., p. 4, 1868.

He found this ridge to be a raised beach, and to contain not only chalk flints, but many modern marine shells, whelk, trochus, cardium, patella, venus, &c., and supposes a late glacial depression of at least 100 feet. He never found any shells in the drift of the centre and south of Ireland.

[The ridge has not the contours of a kame, and is more like a bar, or beach cut off to seaward. It is not a kame, but is merely an eroded bank of sand.]

Youghal to Cork

[After passing Youghal, a large flat is traversed (the limestone valley of Castlemartyr). Some drift is seen, but it makes no prominent ridges, and no true till is noticed. Stratified pebbly drift occurs in a valley, at Killeagh.

There is a large ridge, running parallel with the railway, of stratified sandy and pebbly drift resembling the Trenton gravel, finely exposed at Middleton. Here long cuttings, a quarter-mile long and 50 feet high, are made for gravel. Flow and plunge structure, &c., are shown. It is a true river gravel, resting on limestone, at an elevation of 60 feet. No large erratics, glaciated surfaces, or till are seen, and the region seems non-glaciated.

At Queenstown Junction, at the sea-level, are large masses of clayey drift, somewhat resembling till. More drift occurs west of the junction, but sharp rocks appear below it. There are no signs of glaciation. I now think that Cork cannot be glaciated, notwithstanding the supposed glaciated surfaces seen at Queen's College.

(P.S. The edge of the Killarney ice-sheet stopped at Kilcrea Abbey, ten miles west of Cork. The Middleton gravel is therefore due to a glacial river.)]

Cork

[I re-examined the supposed glacial markings preserved in Queen's College, and took a tracing of them. The markings are on limestone from the vicinity of Cork (Farranmacteige, Jenning's Quarry). The limestone was smoothed off and marked not by long parallel striæ like glacial striæ, but by more irregular markings, none of which were deep. The smoothing off was shallow, not touching all parts of the surface, and as the minor depressions were rough it appeared to be very superficial.

It seemed as if the limestone was smoothed simply by the water and pebbles which were washed over it. The striæ were also made by the moving pebbles, the limestone being quite soft and easily scratched. It is very interesting to see how closely true glacial striation can thus be imitated. President Sullivan, of Queen's College, informed me that these markings were only seen in one or two places, very locally. The elevation of both these localities was less than 75 feet above the sea.

A drive over the adjoining hills of red sandstone and about Cork showed no trace of glaciated surfaces or of till. Broken rock came to the surface. On the north side of the red sandstone hill to the north of the city are large deposits of stratified drift, at an elevation of 200 feet. These lie in a depression and mark an old water-course. Sand and gravel are quarried from these banks, which are well exposed, and resemble the material of kames.

(Note. Write a paper on imitative glaciation. (1) Gravel-made striæ here. (2) Creep striæ. (3) Plough marks. (4) Calamites. (5) Slickensides. (6) Creep of rock surfaces. Refer also to weathered trap and granite (concentric weatherings), and to the distinction between till and water-made clays and sands.) Large streams of fresh water appear to have swept over this region. No shells occur in the drift. The ground is now sinking.[1]]

Mallow to Tralee

[About Lombardstown some rounded pebbles were seen at an elevation of 200 feet. There is clearly some stratified drift in the valley of the Blackwater here. This same deposit is followed along to Kanturk, where it seems to be made of coarser material. West of here the valley is full of it, and we are clearly following an old gravel stream, leading from the moraine of the Killarney glaciers. The gravel is deep west of Millstreet, often 40± feet, although rock sometimes comes to the surface. Shortly before reaching Headford we enter the true moraine—great heaps of till covered by large boulders, making a rough uneven country. These moraine heaps continue to Killarney. Beyond Killarney are great heaps of stratified drift 50 feet or more high, followed by hills of till covered with boulders. The till soon ceases and rocks outcrop. Scattered boulders continue for a while, and finally cease before reaching Farranfore, the moraine proper having been close to Killarney.[2] The moraine of the Killarney region has now been crossed twice on either side of Killarney Station.

---

[1] Peat bogs containing trunks of trees extend out at Youghal under the sea, the stumps being exposed at low tide; evidence of the sinking of the land.

[2] Fringe beyond.

South-east of Gortatlea is some stratified drift, water-worn. None is seen beyond here. I drove about Tralee and on the hills 400 feet high, finding no drift. On the hills sharp rock (Dingle rock) came to the surface, broken up, and the soil was made of the underlying rock, not a pebble or a transported fragment being seen. The country is clearly non-glaciated. I then drove north and east. To the west in the mountains, in Curraheen ravine, was a local glacier, with its own glacial lake and semicircular terminal moraine.]

Tralee to Limerick

[Immediately north of Tralee the limestone comes to the surface with no trace of drift upon it, as is well shown in fresh cuttings on the railway. Then Dingle shales follow, also with no drift, but making their own soil. The ground here is often only 100 feet above the sea, and is close to Tralee Bay, yet no sea nor icebergs have come in here. Why, then, should they have come up the Shannon, as Mr. Kinahan supposes? No trace of any kind of drift was found at Ardfert, 150 feet high. Fresh cuttings beyond also show no trace of drift or pebbles. But just beyond on lower ground, and before reaching Abbeydorney, at 50 feet elevation, is a deposit of stratified drift, clayey, like that in the valley at Cork. There is here a low ridge of stratified drift, an old water-course. Lixnaw is only 25 feet above the sea, yet there seems to be almost no drift here, and the rocks stand out bare. Some limestone quarries just beyond show an entire absence of drift. Near Kilmorna, at about 200 feet, are deposits of clay holding some rolled stones lying in broken and decomposed rock. (Like the Philadelphia brick-clay ?)

There is more of this yellow boulder-bearing clay farther up the Feale, about Abbeyfeale, at 175 feet. On getting to the higher ground beyond, I see that the clay results simply from the decomposition of the rock in place. Rock is seen in sharp fragments as at Devon Road, at 300 feet. The railway goes up to an elevation of 650 feet, where is no trace of drift of any kind. There are many exposures of broken rock, about Barnagh, at 630 feet. There is no drift at the tunnel. The rock shows concentric weathering.

Masses of gravel and of boulder-bearing clay are seen on descending to the limestone valley before reaching Newcastle, at 225 feet, the boulders being often over a foot long. Beyond Newcastle are some boulders in the fields, but the limestone often outcrops. Half a mile below Rathkeale is a heap of drift (moraine, or is it limestone?) filled with large boulders. (Too dark to distinguish it clearly—9 P.M.) Large limestone boulders and clay often occur on the slopes of a limestone outcrop.

According to explanation of the *Geol. Survey*, striæ occur south of Limerick.]

Belfast to Portrush

[Half a mile before reaching Antrim, a ridge of stratified drift is passed. A fine section is exposed on the railway, coarse gravel within, fine on top, all waterworn (at Antrim Station is a perfect round tower). A series of parallel drumlins or eskers occur in the valley about Killagan. These lie beside one another in long parallel rows, parallel to the railway, and also apparently to the axis of the wide valley. They are heaped up like the billows of a chop sea just beyond Killagan, and where cut through by the railway are seen to be made of a compact mass of boulders. They are probably drumlins, or an overridden moraine, and are finely shown here.]

Portrush to Giant's Causeway

[Between the Giant's Causeway and Portrush, near Portrush, are curious blown sandhills just back of the beach, forming a tumultuous series of small hummocks.]

Buncrana to Malin Head, &c.

[The rocks are rounded and glaciated about Buncrana. The striation is from the south-west (?) Striæ are seen on the south side of the hill of Aghawell pointing N. 45° W. The dip of almost all the rocks in the peninsula of Innishaven is to the south-east. No reliance can therefore be placed on the shape of roches moutonnées as to the direction of glaciation.

Within a mile north-north-east of Buncrana, on top of a low hill, are rounded 'tors' of quartz sandstone with striæ, going N. 40° E., and apparently going north-east out of the bay.

Boulders are abundant at the north end of the Gap of Mamore.

Striæ were found on the rocks at the highest point of the gap.

Fifty feet above the striæ point through the gap, going on the side of the rock face north and south. Striæ going in the same direction are seen on the north side of a rock. The rocks dip 38° S., 35° E., producing an effect like roches moutonnées made by ice coming from that direction. Several hundred feet higher up on the cliff striæ go S. 15° W. The elevation is about 1,000 feet.[1]

On the north-west side of a cliff of quartzite, on the cleavage face which dips 54° N., 15° W., striæ are seen going up (or down) the cliff diagonally, running S. 45° E. From the direction of the striæ probably nearly north and south. Again at the north end of the gap, a similar place on the north side of a rounded 'tor' shows striæ going S. 10° E. These are all poor and doubtful.

A fine example of striation, where the striæ are often over an inch wide, and several feet long, is seen on the north-west side of a cliff of sandstone on the north side of the gap. The grooves cross the rock diagonally, going S. 15° W. and N. 15° E.

The rock is well grooved on the north side ; on the north entrance to the gap some white quartzite is ground off flat on top, the striæ going S. 3° E. exact (magnetic). On another rock we again have S. 3° E. (or N. 3° W.) Again in another place S. 7° E., apparently going towards the gap.

---

[1] Measured on top of the mountain east of the gap.

At the village of Claghan are heaps of drift, made of boulders of sandstone, quartzite, and diorite. The sandstone is red, brown, and white. Fragments of a soft ferruginous rock also occur in the drift. This is in the valley, and the soft rock probably underlies it.

Great masses of drift are piled up on the north side of the mountain.

Boulders of coarse red granite or syenite, like the one at Londonderry, occur abundantly just beyond here in the walls. They came from Dundaff Head (?) which lies to the north-north-west.

Striæ N. 8° E. occur at Glen House, near Clonmany, on sandstone rock north-west of the house near the road.

Just below the bridge at Malin is a boss of diorite, magnificently scored. The scorings are several feet deep, forming great grooves in the hard stone which is finely polished. Mr. Close has referred to this as the finest roche moutonnée that he has seen.

The scorings and striæ go N. 40° W.

The rock is at the water's edge. There is a remarkable groove backward half a mile south of Bree; the striæ on the diorite go N. 10° W.; the exposure being very limited the direction is not exact.

At Ballyliffin are numerous boulders of a metamorphic igneous rock, containing blades of hornblende.]

Malin Head

[There is quartz rock on the road near Bally, with striæ going N. 20° W. A dyke of greenstone has fine roches moutonnées which point to north-north-west on the shore. Quartzite at the foot of the hill on which the signal tower stands has grooves pointing N. 20° W., and is finely smoothed.

The hill on which the tower stands is strongly glaciated on the south-south-east side, and crags on the north-north-west. All the roches moutonnées crag to the north-north-west, and Mr. Close is evidently correct in stating that the ice moved off to sea to the north-north-west from inland. The rocks here dip north-west, yet are glaciated against the dip.

My ideas concerning glaciation have now been completely revolutionised. I came to Ireland expecting to find it glaciated from the north. I find instead a complicated system of ice-streams. A Scotch sheet invaded the eastern corner of Ireland, going down to Belfast. The ice-sheet of the interior radiated off in all directions. I now am inclined to believe that the American ice-sheet really started in the Hudson Bay depression, which gradually filled up with ice and then overflowed. The ice probably went northward in Labrador. But what do the reports of the Scotch boulder committee mean?

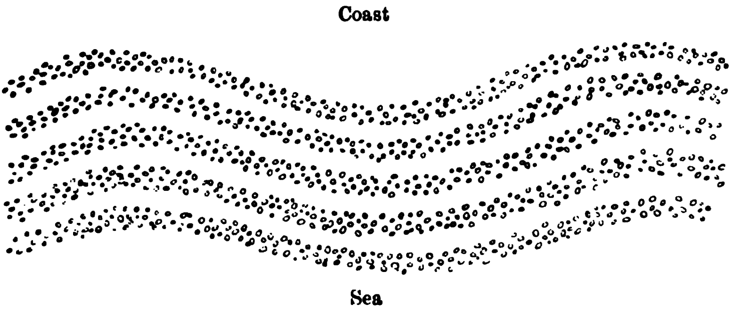


FIG. 15.—Parallel Lines of Pebbles arranged by Waves, one mile south of Malin town.

About one mile and a half north of Malin town is a remarkable accumulation of sand dunes.[1]

There is also on the beach a curious arrangement of pebbles by the waves, some 30 to 40 parallel lines of coarse stones (3–4 inches), each a foot broad and 2 feet apart, following the curves of the coast.

---

[1] For sand dunes on the north-west coast see *Murray*, p. 108, and Kinahan's *Geology of Ireland*.

About one mile south of Malin town the rocks at the water's edge are finely scored, the striæ going N. 35° W. Grooves several feet deep were made by the ice coming on from the south-east. One great groove, a yard wide and 2 feet deep, is circular and is clearly marked by smaller striæ. It swerves around a boss of rock.

The rock is greenstone.

Mr. Close has mentioned this place, *Jour. Geol. Soc. Ireland*, i. p. 217, or at least a place close to it. His locality is quartz rock. This is greenstone.

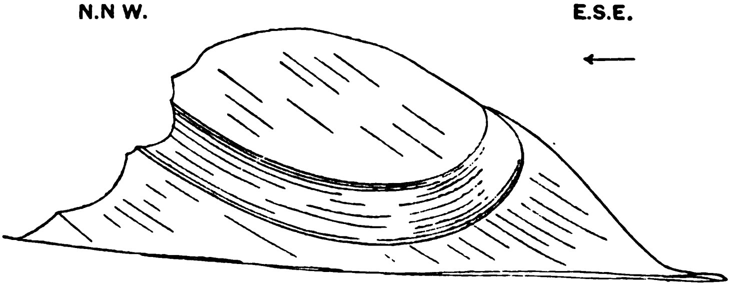


FIG. 16.—Glacial Groove on Rock, one mile south of Malin town.

On the main road from Carndonagh to Buncrana, nearly midway, half a mile east of two lakes at the watershed, are polished rocks, striæ imperfect, going N. 70° E. or N. 75° E.

This is just N. 10° E. of Slieve Snaght. The two lakes, one on each side of the road, are on the east side of the watershed. The watershed is made by an interstratified dyke of diorite (?). The valley up to within a mile east of here is filled with drift. A great stream of ice moved north and east out of this valley. Slieve Snaght and the adjoining hills, together with this watershed, formed a great snowfield.

Did the whole ice-sheet of Ireland move out on this watershed or did it only drain a local snowfield? The watershed is 500 feet high.]

Rathmelton to Millford

[In the village of Rathmelton, Bridge End, or just above the stream, back of the hotel, are some admirable examples of 'roches moutonnées' with striæ bearing N. 30–50° E.

Glaciated surfaces are seen north of Lough Keel. The striæ go north-east. Mr. Kinahan has mapped the striæ about Rathmelton, and I have transferred his marks to my map.]

Letterkenny to Pomeroy

[A large mass of till cut by the railway lies just east of Letterkenny. Other large till hills (drumlins?) occur west of Pluck, where large granite boulders are in the till. Till hills lie all along the railway, also stratified drift. There are hills of till also at Newtown Cunningham.

Hills of till with many large boulders exposed are seen about Victoria Bridge.

A fine series of sandy drift hills (kames?) follows the railway, south-east of Six-mile Cross.

Huge drift hills, the largest I have ever seen, lie between Pomeroy and Carrickmore, piled up some 400 feet high. They are of stratified and unstratified drift. Fine exposures. Enormous accumulation. They are part of a great moraine (?), 300 feet high, and are covered with large boulders. It seems to be a terminal moraine.[1] There is till and drift to the west of it.

Several lakes are in the moraine. This is all high country, and there is no water-level.

Moraine lakes, Lough Brackern, Lough Ocloggan, &c.

Very large kames lie to the west, going west by east.

The rocks are completely concealed by drift from the moraine west to the top of Creggancouree. Immense kames are about Lough Cam, the largest I have seen. Lough Cam is inclosed in a series of ridges.

---

[1] This is probably a moraine made at the meeting of two glaciers, one an Irish and the other a Scotch one; one going north, the other south, perhaps (1886).

Half a mile north-east of Creggancouree are boulders of coarser diabase (?), carried apparently from the mountain towards the north-east. I find boulders measuring 6 feet × 6 feet × 6 feet.

Beyond Lough Cam is another immense kame, part of the same series, enclosing several small lakes.]

Omagh to Sligo

[The gap through the Ox Mountains, which are of gneiss, clearly shows by the 'roches moutonnées' that the ice went northward here.]

Sligo to Rosse's Point

[Numerous boulders of gneiss from the Ox Mountains occur all about Sligo and Rosse's Point, whereas south of the Ox Mountains, at Collooney, these boulders do not appear. The ice movement was therefore undoubtedly northward.

(In the sand dunes here I found many shells of foraminifera.)]

Sligo to Galway, viâ Mullingar

[Kames, one of which is well exposed by a cutting, are seen about three miles north of Ballymote.

In the great central plain between Mullingar and Galway drift is not so evident until Galway is approached, when drumlins with many boulders appear.

According to sheet 105, it would seem that the shape of the drumlins may indicate the direction of glaciation—the broader and larger end being in the direction toward which the glacier moves, and the pointed end in the direction from which the ice came. Yet the opposite is stated to be the case in the paper of Kinahan and Close on the *General Glaciation of Jar-Connaught*, 1872, p. 7.]

Aran Islands

[These are remarkable examples of the post-glacial erosion of carboniferous limestone. The islands are all composed of limestone, which in the glacial age was planed down smooth by the ice, like a floor. Since then the rains have acted upon it like so much sand. Furrows, several feet deep and several inches in diameter, have been worn in it, holes eaten through it, and glacial erratics of sandstone and granite left standing on elevations of limestone as on pedestals. Many of the boulders are of sandstone.]

Athenry to Limerick

[South of Athenry, and from there to the vicinity of Ennis, there is every sign of intense and recent glaciation. Thousands of boulders and fragments of limestone cover the land, the till is deep, it is heaped up in ridges, and is filled with large erratics of limestone, granite, &c., and no water-made gravel is observed. Frequent drumlins are seen. The ridges of till begin about two miles north of Gort. A series of drumlins are seen at Tubber and Crusheen, many good ones being observed at the latter place. A very symmetrical one occurs south of Tubber.

Many drumlins to the south of this are long and narrow like a porpoise. (Fig. 17).

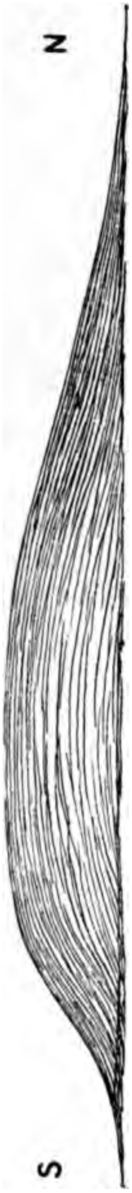


Fig. 17.—Drumlin, south of Tubber.

Most of them, I think, tail to the north and head to the south, i.e. they end most abruptly, and are largest at the southern end, toward which the ice moved. Thus they resemble the 'roches moutonnées.'

North of Ennis some railway cuttings show these drumlins to be full of large glaciated boulders.

The whole aspect of the country changes

on leaving the region of these drumlins and approaching Ballycar and Newcastle.

The boulders become scarce, the fields are no longer covered with stones, glaciated surfaces of limestone no longer appear, and till is only occasionally exposed.

Many places show no signs of glaciation.

At Six-mile Bridge limestone comes to the surface with no till or signs of glaciation. There are no large erratics. The glaciation was much slighter here than in the region farther north.

Yet half a mile to the south is a cutting through drift, and then large hills of till are seen, like a great moraine.

At Cratloe there is red sandstone exposed with almost no drift on it, but just south of that place there are cuttings through till.

Hills of waterworn (?) drift are seen still farther south, but there are none at Long Pavement.

All this is very unlike the intensely glaciated region farther north.]

Limerick to Pallas-Grean

[From the train the limestone plain south of Limerick seems to show no signs of glaciation, but on getting out at Dromkeen, and walking up to the hill called Dromkeen (436 feet high), I find till on the northern side exposed on the road, and containing scratched pebbles, boulders of limestone, old red sandstone, &c.

No striæ were noticed on the rocks.

At Lingfield is a fine vertical cliff, 60 feet high, of columnar trap.]

Limerick to Charleville

[There are cuttings through the till at one mile south of Limerick, at two miles south at the bridge, and at half a mile north of Patrick's Well. At Patrick's Well, where large boulders are in the till, a fresh cutting shows the till to be 20 feet deep.

Farther south the till is thin, limestone often coming to the surface, as is shown in the quarries along the railway, but hills containing boulders occur just above Bruree, and till is seen at the station.

A nearly level plain, through which limestone sometimes projects, continues to Charleville, which is on a hill. At Charleville Station, at the siding, till containing boulders of limestone, sandstone, &c., is exposed, the boulders being often glaciated.

The town of Charleville, to which I drove, stands on a hill covered by clayey till, containing numerous scratched and rounded boulders of limestone.

Boulders of sandstone, &c., also occur, and the sidewalks of the town are paved with glacial cobblestones. It is clearly glaciated.]

Kilkee, Tarbert, and Listowel

[All along the Shannon, on both shores, from a mile below Limerick to Tarbert, hills of till occur. Two miles south of Tarbert is a ridge of till running parallel with the Shannon.

A drive from Tarbert to Listowel showed that there was a covering of bog, and probably till all the way. A pebble of granite was found in the till two miles north of Listowel. Pebbles of flint from carboniferous limestone were also seen.[1]

The till was found to be continuous from Kilrush to Kilkee.

A good section of till is exposed on the road between these places, about two miles north-west of Kilrush.

At Kilkee, on the cliffs on the south side of Moore's Bay, fine glacial striæ are seen, well preserved, covering flat surfaces of sandstone.

Directions are N. 35° W., N. 38° W., N. 34° W., N. 40° W., N. 34° W., N. 36° W., N. 35° W.

The mean direction is N. 36° W. (magnetic).[2] As is shown by the shape of the scratches, the direction is *toward* the north-west, and out to sea. The broad, blunt ends of the striæ are at their north-western ends. Thus—

---

[1] Fringe?

[2] True N. 58° W.

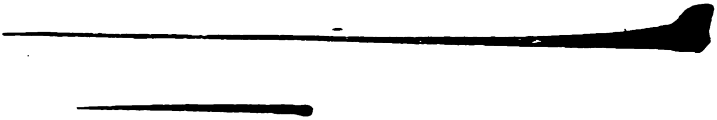


FIG. 18.—Glacial Striæ at Kilkee.

Till was seen all along the coast south of Kilkee. A boulder of Galway porphyritic granite was found two miles north of Tullig Point.]

Striæ (according to the Explanation sheet) occur on Loop Head, on the shore of the Shannon near Ross, and also near Kilcredaun Point, going east and west.

[A stream of ice has, therefore, gone down the Shannon, and opened out in fan-shape near the mouth of the river. Clearly no current went *in* the Shannon, as Mr. Kinahan supposes (*Journ. Roy. Geol. Soc., Ireland*, 1866–67, i. p. 204). The granite erratics have had a circuitous course, going first south-east, then south, then west, and finally north-west.

The movement of the ice was fan-shaped, like that in Wisconsin, as worked out by Professor Chamberlin.

There were many local centres all coalescing, the ice flowing out in the direction of least resistance. There is a full and excellent description of this in Close and Kinahan's paper on the glaciation of Jar-Connaught (p. 18).]

Caher

[At Tipperary a good kame is seen from the railway. This kame, with similar ridges of stratified drift, probably belonging to the same system of kames, is seen beyond the town, running along the railway, and at one mile south-east of the town it is finely heaped up in a series of knolls. These winding ridges continue along the railway for some miles, and are sometimes cut by it, so as to show a structure often coarse above and finely stratified within—moraine.

Beyond Bansha there is a nearly flat plain until the railway approaches the foot of the Galty Mountains, where long ridges of stratified drift again appear. These continue nearly to Caher. Just west of Caher a good section shows obliquely stratified sand and gravel within, and till on top, some 8 feet thick.[1]

A scratched boulder of limestone was found here at the end of the Galty Mountains.

Having driven from Caher west, along the south side of the mountain, I find till with limestone boulders on the south side of the end of the mountain close to Caher. Beyond this, to the west, are some low hills of drift. Boulders of sandstone cover all the valley, but it is difficult to say whether it is all glaciated or not. There is till with scratched pebbles at the village of Garryclogher, three miles west of Caher, a section being exposed by the road. The drift makes a low hill here.

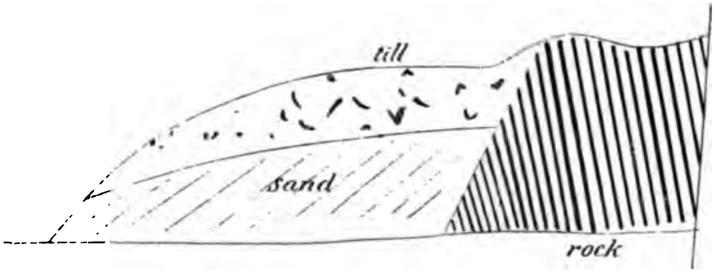


FIG. 19.—Section of Obliquely Stratified Sand and Gravel west of Caher.

Farther west the drift on the limestone does not look like true till.

There are no glaciated boulders of limestone here (such as those about Limerick), the only drift observed being sandstone boulders, on which are no scratches. Moreover, they are not imbedded in clay, but rather in a sandy impure detritus or wash, and a stratification can be seen.

---

[1] Have not these sands been transported by the River Suir from a glaciated region farther north?

The whole resembles the water-borne drift in Butler Valley, Pennsylvania, south-west of the terminal moraine. Probably this is only wash, the result of floods, and possibly the hill three miles west of Caher is then the *moraine*, but I think not.]

Knocklong

[Driving south from Knocklong, after passing some flat land, I find hills of stratified drift, till, sand, and gravel at Ballyfruta, about one mile north of Ballylanders. Here are cuttings for sand and gravel, and in these I see pebbles of Galway granite and boulders of greenstone, identical with that collected in place at Lingfield. These sand-hills are a line of hummocks and winding ridges, running parallel to the base of the mountains, and continuous with those which run south of Charleville and Kilfinnane. They may represent the terminal moraine, being like the moraine in Minnesota, &c., on a small scale. These hills taken together are about a mile in width, and extend to within a third of a mile of Ballylanders. According to the Explanation Sheet for this section, there is no drift in the silurian area south of Ballylanders.

The above drift may, however, be the aqueous fringe.]

Abbeyfeale

[On the way to Abbeyfeale I noticed till with limestone boulders exposed at Patrick's Well, Rathkeale, and Newcastle. At the latter place gravel is seen under the till, as at Caher, &c., indicating simply *water under the ice.*

In the valley of the Feale, at Abbeyfeale, I saw a large flat-topped deposit of waterworn non-scratched drift and débris.

One mile east of the town is a drift deposit, exposed in the railway cutting, closely resembling true till, as some of the stones are scratched.

Driving south toward Castleisland I cannot find certain evidences of glaciation. There is a large deposit of drift in the river opposite Knocknagashel, which is exposed by the stream, 30 feet deep.

The drift all seems to be local and washed down the valley, as the stones are not glaciated. Yet pebbles of fossiliferous flint occur.

Is it waterwashed till? [1]]

Knocknagashel

[At Headley's Bridge, two miles south of this point, and beyond, there is no trace of glaciation, and southward to the watershed, between here and Castleisland, the soil is made of sharp fragments, and streams cut the rock or rock talus. The carboniferous soft shales are covered by a detritus of sharp fragments of carboniferous sandstone. A specimen of sigillaria was found in this loose sandstone.

From the watershed two miles north of Castleisland I turned back over the hills, seeing no trace of glaciation, but much surface wash or débris, which might readily be mistaken for transported drift.

The harder rocks lie on softer ones, and have a rudely stratified arrangement, the sandstone slabs lying flat, or nearly so, as if stratified by rains and frost. This kind of drift is often quite deep in the valleys, and is an ancient valley drift due to atmospheric agencies. Some of it may be 'avalanche drift,' and the slipping downhill has often scratched the flat faces of some of the sandstone fragments. Some black flints, resembling chalk flints, were found. These probably belong to the coal measures.

I then drove ten miles E.S.E. to Brosna (a town wrongly placed on Hull's map, but correct on the Ordnance maps, being one mile south of Munakilla), and found the region at some 700 feet elevation, entirely non-glaciated and driftless.

---

[1] It is local stuff made when the ground was frozen.

Elevations.—The point at the watershed north of Castleisland is 800 feet. Clydagh River at Brosna 350 feet. I found no sign of drift about Mount Collins on the Feale, or about Munakilla, or on the hills between there and Abbeyfeale. No kames or till or striated rocks or erratics were observed anywhere in the region. Many rounded boulders seen on top of the broken rocks are due to weathering, the nodules in the shale frequently scaling concentrically.

On the way back to Newcastle by rail, I could not detect any drift until between Barnagh and Newcastle, where till, filled with limestone boulders, occurred at the edge of the limestone valley, and continued thence to Limerick. The southern limit of true glaciation must be north of Abbeyfeale.]

Newcastle

[Hills of till occur between Rathkeale and Ardagh and north-west of Newcastle.

From Newcastle I drove to the top of the mountain, 700 feet to 800 feet. The mountain had every appearance of being non-glaciated, but on the top (guided by Jerry McCoy), at Rouska, some four miles west of Newcastle and 800 feet ± high, in a ravine, in a bog, at the head-waters of the River Gale, I found till filled with limestone boulders.

These boulders were often several feet (4 feet or more) in diameter, and were finely striated. There is a lime-kiln here, and the boulders (called 'running limestone') are broken up and burned. Boulders of sandstone and other materials also occur with the limestone boulders. McCoy informed me that 'running limestone' was found in the ravines on the east side of the mountain below Barnagh, in a ravine behind Garryduff House, also north of here in ravines at the head-waters of the White River, and at Newtown Sandes. This deposit of running limestone is genuine glacial till, and represents the *terminal moraine.* Both here and about Barnagh it is covered by the local sandstone detritus from the slopes of the mountain. The ravines near Barnagh seem to be non-glaciated.

Glacial action appears to have been very *weak* at the extreme edge of the ice-sheet.

I have noticed a great difference in the *intensity* of glaciation at different points.

The most intense action is where the glacier was confined to small local streams, or where it was deep and long-continued. It is generally more intense about sea-level than at higher elevations.

It is very weak all along the edge of the great Irish ice-sheet. It is very intense at the sea-level at Malin, in Galway, and at Derrynane and Glengarriff.

The local glaciers of Dingle made intense glaciation. The Killarney glaciers where flowing out to sea were very intense, as witness the glaciation at the end of Kenmare Bay.

In America we have intense glaciation, as is shown by the deep grooving about the great lakes and the St. Lawrence valley, but weak glaciation about the edge of the ice-sheet, as in Pennsylvania. Deep grooves are rarely seen in Pennsylvania, the rocks being merely 'sand-papered' on the surface, as it were, and no change in the topography was effected.

(Write a paper on the varying intensity of glacial erosion. Study it carefully in Switzerland. Study, also in Switzerland, kames, drumlins, shapes of striæ, &c.)

An ice-sheet at its edges fills up rather than erodes, being thus like a river.[1]]

Adare

[A finely glaciated boss of limestone has been cut through for the railway half a mile east of Adare, striæ appearing on both sides of the rails.

---

[1] *Intensity of glaciation.*—Penck, in *Die Vergletscherung der deutschen Alpen*, p. 199, Leipzig, 1882, says: 'An ice-sheet heaps up material along its periphery, and erodes in its central part.' [Scandinavia is an erosion region, and North Germany a deposit region; the Alps are an erosion region, South Bavaria and Hohenzollern are deposit regions; county Galway is an erosion region, county Limerick a deposit region; the Lake District is an erosion district, and Cheshire a deposit region.]

The limestone has a fine roche moutonnée structure. The striæ are parallel, or nearly so, varying from S. 5° W. to S. 15° W., mean S. 10° W. Part of the boss is white coarsely crystalline calcite, which is crossed by black striæ, due to moss growing in the scratches. A beautiful effect.

The direction of glaciation is clearly shown by the shape of the striæ to be towards the SS.W. The blunt ends of the striæ point to the south.

Here is a drawing of natural size.

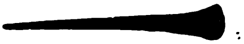


FIG. 20.—Glacier Scratch near Adare.

I use a trowel and a Japanese brush for clearing off the earth and exposing a fresh surface.

Again, a scratch about a foot long shows how the stone turns over, and finally jumps out.

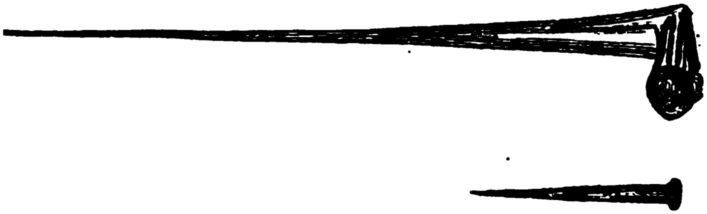


FIG. 21.—Glacial Scratches near Adare.

Sometimes the scratch is shaped like a nail.

Another interesting point which I think is a crucial distinction between glacial and iceberg action, is the fact that the striæ on either side of the roches moutonnées point upward and towards the axial line; in other words, if the axis of the 'tor' is north and south, the striæ on the east side point south by west, and the striæ on the west side point south by east. Here, the axis of the tor being S. 10° W., the striæ on flat surfaces pointing in the same direction, the striæ on the east side point S. 15° W., and those on the west side point S. 5° W.

Icebergs would move off, not close in, on a rising boss of rock, while a solid mass of ice would close in. Get the physical data for this.

Striæ go S. 5° W., S. 8° W., S. 14° W., S. 15° W., S. 5° W., S. 10° W., S. 3° W., S. 15° W.]

St. Patrick's Well

[The till at this place lies on a glaciated surface of limestone. Striæ are seen just east of the station near the stone bridge crossing the rails. It is a flat surface with parallel striæ.

Striæ go (magnetic) S. 15° E., S. 14° E., S. 13° E., 10°, 20°, S. 15° E. Mean S. 14° E.[1]

The large boulders also have their longer axes lying in the same general direction, their smaller ends projecting from the till. S. 13° E.

These boulders are scratched, and measurements of the direction of the scratches give S. 3° E., S. 7° W., being the same general direction. Striæ are seen on several surfaces going up the inclined strata of limestone which dip north.

On the rock surfaces the broad ends of the scratches point to the south.

The striæ and boulders are nearly at right angles to the railway.

Most of the boulders are of limestone.]

Charleville to Ballyagran and Darragh

[One mile east by south of Charleville a low ridge of till runs (map) N. 70° E.

Large boulders are here, and south of this locality is a series of flat rolling hills of till, with much 'running limestone' in glaciated boulders. It is a high rolling country, but not hummocky.

In the grounds of Mount Russell House, however, on the roadside, are characteristic drift hummocks and a kettle-hole. Most of the pebbles and boulders are of limestone, but many of white and red sandstone, and of brecciated conglomerate, &c., also occur. The underlying rock is old red sandstone.

---

[1] True S. 36° E.

Rolling drift hills full of limestone boulders occur at Craigue cross-roads south of the road. Still higher hills of limestone pebbles are seen just east of here, the road ascending them part way.

At Ardpatrick are more limestone pebbles and boulders in abundance, and a gravel pit and hills of the same drift lie to the south.

Going southward from Ardpatrick limestone boulders occur (one being of greenstone), but though at first very abundant, they gradually decrease in number, until at Castle Oliver and Glenosheen, two miles south of the drift hills at Ardpatrick, they almost entirely disappear. No till is seen south of Glenosheen. The soil about Ballyagran is made of broken silurian shales. A top earth, a foot or so in thickness, contains a few rounded boulders. A single boulder of limestone was found, and a pebble of gneiss. Both were waterworn, and had been carried by the rains, &c., as the region shows no signs of glaciation. Gray grit is quarried about Ballyagran, but there is no drift on the top.

I go eastward from here towards Darragh. A beautiful silurian valley surrounded by mountains is seen. It is like a Pennsylvania Appalachian valley. An anticlinal valley.

It is entirely driftless.

The limestone pebbles found about Ballyagran were brought there by man for paving from near Kilfinnane.

There are fine sand-pits at Castle Oliver, which therefore marks the southern limit of the drift.

At Darragh I turn northward towards Kilmallock. No drift elevations are seen about here.

Ballyagran is 500 feet high.

Where I turned off near Darragh the elevation was about 600 feet.

I ascend the road between Darragh and Kilfinnane to nearly 1,000 feet, to the picturesque archway which crosses it in the Castle Oliver demesne. Here there is no trace of drift.

A deep cutting made for the roadway shows silurian slates coming to the surface.

The hill just above is 1,222 feet. It is a beautiful road cut on the side of the mountain.

No drift is seen until approaching Kilfinnane. The edge of the drift is well marked, but no distinct ridge of drift hills occurs along the boundary entitled to rank as a terminal moraine, such as there is in Pennsylvania. From Kilfinnane I return to Charleville.

I suspect that this is the southern edge of the fringe, and that the true moraine is farther north. The Shannon being dammed up by ice, the rivers flowing northward from Kilfinnane would be dammed up also.]

Listowel

[In a ditch by the roadside, two miles north-west of Listowel on the road to Ballybunnion, I find till with pebbles of Galway granite, sandstone, limestone, &c.

Some of them, especially the limestone pebbles, show scratches on them. This is at the River Galey.

I drive south of Listowel for several miles without finding a trace of drift, except on the north side of a hill south of the town.

There is no drift on the high ground, the boulders being of sandstone made round by weathering.

On the Castleisland Road, just above the Six Crosses, three miles from Listowel, is the moraine (?). A mass of drift on the edge of the hill. It is partially stratified, showing slight water action.

There are many sharp fragments, others rounded; there are also patches of till in it with striated pebbles, mostly sandstone and shale. A good exposure by the roadside has been quarried.

Immediately above the Six Crosses by the road to Tralee, to Castleisland and to Lixnaw, there is a knob of drift.

Drift forms a deposit lying along the side of the hill like a shore line. The drift hills are hardly discernible.

There is a quarry two miles west of Listowel near Castleisland Road, where the slates overlie the limestone, the junction of the two being seen. Till lies on top of the latter.

The Shannon ice-stream was shallow and thinned out at its southern edge, where it melted rapidly. It thus heaped up no large moraine, but made a deposit in part till, part pebbles, part shingle, laid down on the side of the hill like a beach deposit. Farther east at Newcastle it was thick enough and powerful enough to rise on to the mountain, but here it had lost its force.

It was not thick enough to make drumlins in Kerry, except just south of the Shannon.

This drift, forming the edge of the ice, a sort of lateral moraine, is a kind of drift deserving special designation.

It is two-thirds sharp detritus or débris of the adjoining or underlying rocks, and one-third rounded water-made pebbles, with occasional patches of true till.

The underlying rock is not scored or glaciated. It resembles the drift of the fringe in Pennsylvania, both perhaps being due to the thin edge of an ice-sheet which was melting; or perhaps these are iceberg deposits which obscure the real glacial deposits, the icebergs floating in the water of the melting glacier, like those of the Marjelen See in Switzerland.[1]]

Listowel to Ardfert

[We drive on the road to Tralee. There is no drift at Mountcoal, and no till on the hills. Some of the detritus of the shales and sandstone closely resembles drift, and might readily be mistaken for it. A good exposure of such material occurs at 'Barnmore' on the roadside. The shale is broken into fine splinters and has a horizontal lamination, apparently a sort of gravity and rain arrangement. It is clayey on top, and made purely of local material. Some of the fragments of sandstone in it are well rounded by concentric weathering, thus resembling glacial boulders.

---

[1] Perhaps there is no terminal moraine, because the ice was moving parallel to it i.e. lateral moraines are not so well marked as terminal moraines.

At Abbeydorney is stratified drift in the railway cutting, consisting of pebbles of sandstone, but no limestone. It is therefore not modified till. No limestone rounded or glaciated boulders are seen here, or at Ardfert, or between these places.

On the other hand, limestone outcrops everywhere with no signs of glaciation. The sandstone pebbles are all alluvial.

No till, or ridges, or kames, or striæ are seen. Ardfert is less than 50 feet above the sea.

On the road from Ardfert to Ballyheige, two miles north of Ardfert, rounded boulders of limestone begin to appear in quantity. Most of these boulders are curiously eaten in short, curved, worm-like burrows, as if by a marine worm or mollusk, indicating that they have been in the sea. The elevation here is only a few feet above the sea. There are fine sand dunes here and at Ballybunnion.

Between Ballyheige and Causeway, on the ridge of old red sandstone which makes Kerry Head, I observe no undoubted glacial drift at all, except at Rathmorrell, where drift is exposed by the roadside. There are many boulders, but they are not certainly glaciated. The boundary of the drift is not exact. Probably it runs just south of the town of Causeway, and on the north side of Kerry Head.

According to the Geological Survey drift occurs at Ballybunnion, and limestone boulders are seen on the north shore of Kerry Head, but these latter may not be glacial as they may be nearly in place.

From Causeway back to Listowel no rounded or glaciated limestone boulders were noticed, and the evidences of glaciation were not decisive.]

Caher to Waterford

[West of Caher ridges and knolls of drift are seen following the base of the mountain. The railway crosses them. They are heaped up like a moraine, and are stratified and sandy in the interior, and more or less clayey, like till on the top.

East of Caher no drift was noticed, perhaps because the railway cuttings were grassed over.

But drift till (?) with rounded limestone boulders is seen west of Clonmel.

Although the limestone often comes to the surface, with no till upon it, in other places undoubted limestone till is seen.

There are exposures of till, often containing large limestone boulders, a few miles east of Clonmel.

Heaps of till are seen two miles west of Kilsheelan, near Castle, limestone pebbles abounding. Large masses of till are seen between Kilsheelan and Carrick-on-Suir.]

Waterford

[On the Limerick and Waterford Railway large masses of till are exposed a mile or so outside the town.

Till also occurs on the high cliff of silurian slates capped by old red conglomerate.

Striæ go S. 7° E., S. 20° E., S. 4° W., S. 8° E , S. 15° E., S. 9° E., S. 17° E., S. 17° E., S. 9° E.

Striæ S. 5° E., S. 2° E., S. 20° E. are seen on the red sandstone conglomerate, pebbles of quartz being polished off evenly with the matrix. It is on these pebbles only that minute striæ were detected. They were seen with difficulty, and only by looking in certain directions so as to let the sunlight slant upon them.

Pebbles of quartz thus striated stand somewhat above the quartzose matrix.

Roche moutonnée structure is here also seen tailing to the north, but this is partly due to the dip.]

Cappoquin and Dungarvan

[At Kilmeadan till containing limestone boulders overlies silurian slates, the whole being well exposed east of the station. The most numerous boulders are of sandstone, as sandstone is the nearest formation to the north. There are some beautiful glacial corries in the Commeragh Mountains, there being at least four in sight.

Here, however, glaciated boulders and large erratics are seen.

There is till filled with boulders between Stradbally and Dungarvan, at sea-level at the River Dalligan. There is stratified drift also at Dungarvan.[1]

I drove from Dungarvan north to Knockboy. Stratified drift was abundant in the valley about Dungarvan.

On ascending the mountain at 400 feet, I saw till full of scratched old red sandstone pebbles, lying on red sandstone, which was striated north and south. This locality is near Colligan House, on the road to Clonmel, in a quarry of red sandstone.

The valley lies in the same direction, and these mountains were probably a centre of local glaciation, just as the Killarney region was.

Yet this may be the general ice-sheet, for at 620 feet there is still till, and the valley is seen to open to the north.

---

[1] Large cuttings through typical till lie on the upturned silurian slates north of Kilmacthomas.

South of Kilmacthomas I saw creep towards the north-east, and thus against the glacial movement. I suspect that this bending over of the slate is always due to gravity, and never (?) to glacial action.

Similar creep to the north-east was seen between Kilmeadan and Carroll's Cross.

Again, on the Suir below Waterford, creep is to the north, or, as in all the above cases, downhill.

At 620 feet, one mile and a half south-west of Knockboy at the cross-road, the till overlies a glaciated rock; the striation is not exposed.

This is a depression between the Commeragh and Knockmealdown Mountains, down which a stream of ice came.

The striations on boulders go about north and south.

Neither here nor elsewhere have I seen the shales turned over by glacial action.

Is there such a thing as glacial creep?

At Kilmeadan the slates stood upright, and were overlaid by till, and broken up and mixed with it; but, although standing vertical, they were not at all overturned.

All the mountains, except a few of the highest peaks, are rounded as though glaciated.

I ascend to 825 feet and find the same characters; the glacier seems to have been deep. This region is called the Tampanes.

It is 100 feet higher just beyond here. Elevations, 1,350 feet high, are rounded off.

We go west to Ballynamull, then south along the River Finish to the limestone valley of the Blackwater.

Till is seen along the road to Cappoquin, and just east of Cappoquin is a high hill of stratified drift, consisting of fine sand within and coarse gravel on the top.

The coarse gravel is irregular and almost unstratified like till. It is a sub-glacial watercourse following the valley.

East of here in the valley the stratified drift continues deeply to Dungarvan.

From Cappoquin we go to Mount Melleray, and find boulders everywhere except on the sides of ravines.

Could the Blackwater River have been turned from its course by drift blocking up its channel?

From Cappoquin we go south to Aglish, rounded boulders continuing in abundance until within two miles north of Aglish. Then we turn eastward up the river.

No true glacial drift is observed.

Drift consisting of a mixture of sharp and rounded fragments, some of them scratched, occurs on the sides of the hills. I take it to be 'creep drift' or 'avalanche drift.'

The scratching of the fragments is due to sliding; all the material is local. The soil is a mixture of sand and clay; the fragments have their flat sides down.

It looks like a weather-beaten till. Not tough. There is a good example in an opening in the limekiln one mile west of the R. C. Chapel of Tours.

Just beyond the chapel, at 600 feet, clayey till is seen.

The last may therefore also be till.

The valley is here choked up with drift.

In the till pieces of carboniferous chert containing encrinite stems occur, representing the limestone.

This is on top of Mount Stewart, one of the Drum Hills, 750 ± feet.

The drift is upper till, and no striæ are seen on the rocks.

We descend from the Drum Hills to Dungarvan, and find much drift on the top and northern slope of the hills. The boulders of flint, above mentioned, have been carried from a valley north of this locality.]

2. Second Visit to Ireland, 1886

Cork to Macroom

[At the Capwell Station in Cork there is an exposure of drift, full of boulders. It is gravelly, and overlies the limestone. Exposures also occur a short distance out of Cork on the railway. We are in the valley of the River Lee, and the drift is stratified. No evidences of glaciation (till, moraines, or roches moutonnées) are to be seen about Cork or Ballincollig. At the latter place limestone comes to the surface.

Great banks of coarse drift occur a few feet west of Kilumney Station, near the River Bride. The pebbles in this coarse gravelly drift in large numbers dip up stream, or to the west.

This is due to torrential action.

Half a mile farther east are large masses of drift along the river, rising up in ridges, and a kame-like drift ridge is seen at Kilcrea Abbey. Moraine? Did a local glacier come down the Valley of the Bride to and below Kilcrea Abbey? At Kilcrea Station it is flat, and I see the back of the supposed moraine farther down the valley. Half a mile east of Kilcrea Station, on the south side of the valley, is a limestone quarry, and more exposures of limestone on both sides of the railway occur near Crookstown Road Station, where the land is very flat.

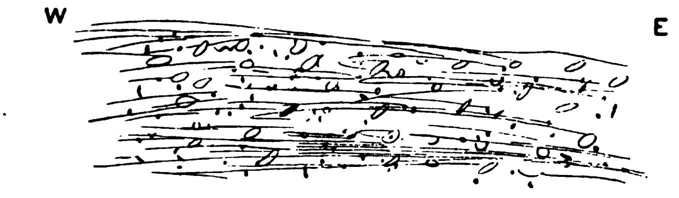


FIG. 22.—Section of Drift west of Kilumney Station, County Cork.

At Dooniskey (in view of 'The Paps') are fine roches moutonnées of red shale. Ridges of the slate are all glaciated and striæ are seen pointing down the valley and away from the mountains. We have crossed a watershed, and the stream here flows north-west, while the striæ go to the south-east. Glaciated erratics of sandstone are also common here. High mountains are seen to the west and north-west. We are in a heavily glaciated region.

I return to Cork.

Below Crookstown I see another exposure of drift, in which the pebbles dip up stream. Between this point and Kilcrea there is evidence of an old lake. This lake, dammed up at its lower end by a terminal moraine, would thus resemble the Italian lakes. It is not yet entirely dry, but is being drained by ditches. It is perhaps half a mile wide and three miles long.

The moraine is finely shown at and east of Kilcrea Abbey. The kame-like ridge at the abbey is part of the moraine, the back of it. Exposures of till occur, and numerous erratics cover the knob-like hills. True moraine contours are seen here. The moraine hills continue from the abbey to within half a mile west of Kilumney Station.

At the station at Cork is a good exposure of sand and gravel. The sand is below and dips eastward, and is fine and stratified, while coarse gravel, irregularly stratified, lies on the top. Wave action is seen, viz.:]

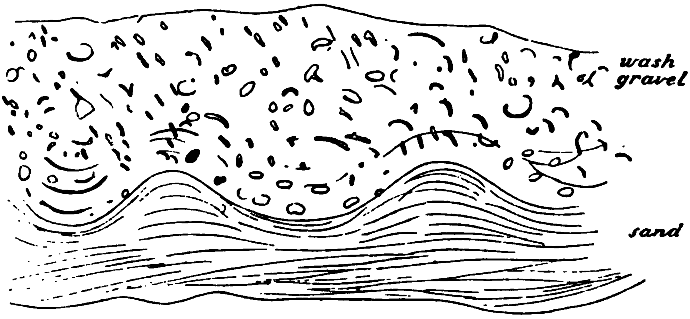


FIG. 23.—Section of Sand near Railway Station, Cork.

Cork to Bandon and Clonakilty

[Drift is found on the limestone at Cork, but after reaching the old red sandstone area I see no drift whatever. Many exposures of red shale occur, where the decomposed and broken rock comes to the surface, uncovered by drift of any kind. This is the case, for example, at Waterfall Station, which is 380 feet above the sea. Nor do I see any drift on the ground made by the sub-carboniferous sandstone. This sandstone forms a soil full of sharp and rounded fragments, as is well seen at Ballinhassig Station, at 350 feet elevation.

Just east of Bandon the River Bandon cuts through deep drift ?

Just beyond Bandon is a cutting through drift.

At Clonakilty Junction is undoubted till, full of scratched boulders, lying on glaciated slate. I take the newly-opened railway to Clonakilty, where are excellent exposures of undoubted till, identical with that in Pennsylvania, being full of sharp fragments of the underlying slate and glaciated boulders of foreign rocks.

Peat bogs now occur for the first time, being characteristic of glaciated areas. Large and numerous boulders lie in the fields. This new railway (the Clonakilty and Bandon Railway) gives an excellent opportunity for examining the glacial deposits. A lake occurs at Ballinascarty. Another lake, dammed up by a mass of unstratified stony till, occurs close to the Clonakilty Union, which is east of the town. Glaciated stones are found about the town, and the terminal moraine goes out to sea farther north-east than Clonakilty. Roches moutonnées were seen in the vicinity.

I return to Cork.

Just before reaching Bandon (i.e. west of Bandon) are deep cuttings through stony till, which is heaped up in moraine-like ridges. In Explanation sheets 194, 201, 202, p. 27, mention is made of transported boulders of greenstone on the hills about Bandon, which have been carried southward from Mishel. I believe the moraine to be at Bandon. The mass of drift cut through by the Bandon River east of the town is the front of the moraine. It is probable that the glacier was drained by the River Lee to Cork, and thence along an ancient watercourse, marked by gravel, to Youghal, by way of Middleton. I think it possible that this was the pre-glacial course of the River Lee, and that the large amount of drift carried down by the swollen river at the close of the glacial epoch choked up the river-bed, so as to cause the river to join the inlet of Queenstown Harbour. This, however, is a mere possibility, and much more evidence should be collected before it can be held to be probable.

A somewhat similar explanation suggests itself for the remarkable course of the Blackwater from Cappoquin to Youghal. In the latter case it may have been a glacier which dumped the drift into the old river-bed, and so turned the water out of its old course and forced it to cut a new one to the sea at Youghal. The River Bandon and the River Blackwater also acted as waste weirs of the melting glacier.

Morainic hills are seen just east of Bandon, and the railway makes a cutting through drift, half a mile west of Innishannon Road Station, but rock occurs beyond, before we reach it. The moraine[1] may therefore be said to pass through Bandon.]

The nearest recorded striæ are those about Dunmanway,[2] where the striæ go to E.S.E. and S. 20° E.[3]

Queenstown

[I go from Cork to Queenstown and thence to Haulbowline Island by boat.

It is clear that the River Lee in glacial times flowed from Queenstown Junction by Middleton to Youghal, as an open drift-filled valley runs that way. Drift which is false-bedded, like that on the hill at Cork, occurs at the head of the river, choking up the entrance to the valley.

No drift occurs at Carrigaloe, opposite Passage, the river making here a narrow rock-cut through the red shale (old red sandstone).

Through the courtesy of Mr. Thomas, Governor of Haulbowline Island, I had an opportunity of examining that island. Professor Hull (*Jour. Geol. Soc.* Ireland, vol. iv. p. 111) states that till occurs here, and mentions the fact as evidence of an ice-sheet having covered Cork Harbour.

---

[1] Of the Killarney ice-sheet.—J. F. L.

[2] Explanation, *Geol. Survey*, sheet 193, p. 18.

[3] See Explanation, 185, 186; 194, 201, 202; 187, 195, 190.

I found a compact mountain limestone containing fossils (orthoceras, brachiopods, corals, &c.), and without cleavage, coming to the surface, and formerly quarried. No glaciated surfaces were observed anywhere.

At the lower end of the island, where there is much 'made ground,' there is an impure clay, full of stones, shells and boulders. The latter are often scratched. None of this is more than 5 feet above the sea. The scratched stones were scratched, perhaps, artificially. At least they were not scratched by a glacier. Here is another case of scratched stones occurring in clay outside of the glaciated area. They probably came from below the sea-level.

A similar case occurs in the Severn, where, during the excavation of a tunnel under the bay, scratched stones were found, as Professor Sollas informed me. I expressed the opinion in Report Z, that scratched stones are characteristic of a glaciated area, but I have changed this opinion, having seen scratched stones at many places in America, Ireland, and England, outside of the region covered by land-ice. Scratched stones abound all over the south of England, near London, Birmingham, &c. I found them on the Susquehanna, back of Berwick, at Oil City (?), Clean Rock City, &c., outside of the glaciated area ; and in Ireland about Listowel, &c.

I found them also in the stratified drift south of Dublin.]

Cork to Waterford

[I went from Cork to Waterford vià Lismore. No trace of glaciation was seen between Cork and Mallow or Mallow and Lismore. No drift of consequence was noticed between Mallow and Lismore, limestone coming to the surface as in the Chester Valley, Pennsylvania. Rounded pebbles occurred here and there in the soil, but no great drift banks were seen. The pebbles are found on hillsides up to, perhaps, 100 feet above the present stream, and the drift is level-topped, and is a loamy soil containing carried pebbles. (This limestone valley is like the valley in Pennsylvania, west of Penobscot Knob.)

The heaps of drift just beyond Lismore are full of large boulders and sharp fragments, though more or less stratified. At Cappoquin true till appears in large mass, and the whole valley is filled up with drift. Farther east, before reaching Cappagh, limestone crags jut up in the centre of the valley, and glacial action is either absent or obscure. Boulders, however, are numerous.

The limestone about Dungarvan is not glaciated.

Stratified drift occurs at Dungarvan.

Evidence of local glaciers north of Dungarvan on the coast is shown by the heaps of stony drift and numerous erratics. A glacier came from the Commeragh Mountains to Durrow Station, south of which is its moraine. This glacier went S.S.E.[1] There is no evidence that the central ice-sheet got across this great wall of mountains; but local glaciers arose in them, and went to the sea. Semicircular moraines close to the mountains are quite distinct north of Durrow (Stradbally) Station.

The mountains die down some time before reaching Kilmacthomas, and there can be no local glaciation here. No glaciation is evident, but if it does exist, it may be due to the ice-sheet extending to the coast (north of the Commeragh Mountains). There are no mountains between here and Waterford. The district seems to be non-glaciated. There are numerous fresh exposures, but I cannot satisfy myself that there is any true till. The many fragments in the soil look as if they were merely frost-broken and weathered pieces of the underlying rock. An excellent fresh section of what looks like till occurs just south of Kilmeadan Station. Great blocks (boulders ?) of conglomerate are seen in the drift (?) reposing on shale. It looks quite like morainic drift.]

---

[1] There is a deep lake in the Commeragh Mountains.

Waterford to Clonmel and Thurles

[The rocks just west of Waterford are glaciated. Then follow cuttings through stony till. Limestone, red sandstone, and other boulders occur. There are rounded hills, but no high mountains to the north. This country seems to have been covered by the general ice-sheet. Deep till occurs almost continuously from Waterford to Fiddown and Portland Station, and the rock rarely outcrops. The red sandstone hills north of this station are certainly glaciated, and those to the south are probably so. Does the moraine run by Rathgormuck, and the north-east side of the Commeragh Mountains?

The top of Slievenaman Mountain may have been an island rising through the ice-sheet, although the whole mountain is rounded, as if glaciated.

A fine moraine, heaped up in great hummocks, and full of limestone boulders larger than a man's head, is well exposed on the railway, south of Slievenaman (2,264 feet), and half a mile east of Kilsheelan Station. The high jagged ridge of the Commeragh Mountains is seen to the south acting certainly as a barrier to the ice-sheet. Slievenaman, from its smoothed appearance and from the absence of corries, would seem to have been surrounded by ice, and not to have been the source of local glaciers. Just west of Kilsheelan, in the region of Slievenaman, rolled limestone gravel occurs, but the limestone below does not seem to be glaciated. Heaps of very coarse limestone gravel, however, occur a mile farther west.

At Clonmel I get out and walk to Mount North. I find rounded boulders and pebbles of limestone extremely numerous in the fields. With these are fragments of red shale, pebbles of sandstone, a pebble of Galway porphyritic granite, and a boulder of red felspathic granitic rock, made of orthoclase and felspar, resembling the crystalline felsites or quartz porphyries of Galway. The limestone is decomposed on top, and shows no striæ. It is full of fossils, and I collected euomphalus (?) spirifer (?) productas (?) orthoceras, terebratula, &c.

It cannot be proved that the drift here is ice-carried. It may be due to a 'wash' from a true moraine farther north. It may be that this is the case also at Charleville, while the true moraine is north of Limerick Junction.

I now climb the mountain south of Clonmel, a mountain of old red sandstone. I find on it no trace of drift of any kind. Not a single limestone boulder or pebble occurs in the soil,[1] which is made purely of broken fragments of the underlying rock. It is not glaciated.

I take the train for Thurles. We first cut through limestone which is apparently non-glaciated. We then come to limestone boulder drift in patches, apparently stratified, and farther north to a great thickness of till full of limestone boulders forming the highest point of the railway, where deep cuttings occur. This is just before reaching a point opposite Slievenaman, and is perhaps the terminal moraine of the central ice-sheet. Large limestone boulders abound from here northward.

Farther north we get into soft shaly coal measures, on top of which is till full of limestone boulders. At Fethard the limestone again appears, and is here glaciated, while a quantity of limestone drift, stratified and unstratified, is seen. A deep covering of limestone drift covers the country from Fethard northward. Glaciated surfaces of limestone with striæ occur on the railway just south of Laffan's Bridge Station.]

Dublin and Vicinity

Expl. Geol. Surv., Ireland, to sheets 121–130, contain on p. 47 a list of literature by Prof. E. Hull, LL.D. &c. &c.

Sir H. James, Note on the Tertiary Deposits of Co. Wexford. *Jour. Geol. Soc. Dub.*, vol. iii. p. 195.

---

[1] The occasional limestone pebbles which occur in the road bed and which are at first sight misleading, have been carried up during the hauling of manure.

Tertiary fossils extend from the northern boundary of the county near Arklow along the whole line of coast as far south as Kilmore and inland as far as Gorey, Ferns, and Enniscorthy, i.e. forty miles long by eight broad. On the side of Forth Mountain they go up to 400 feet, and are 174 feet thick at Blackwater. At Ballygorey, Rosslare Harbour (in the Forth, south of Wexford), and in the cliffs on the coast is a dark tenacious clay, resembling London clay, which is clearly marine, as shown by the rows of Nullipora and undisturbed delicate shells like Fusus bamfius. These shells are found in the most perfect state and were never disturbed. This tertiary deposit was preserved by its position with reference to the Wexford and Wicklow Mountains from the denuding action of the northern drift. Deposits of sand and gravel lie over these tertiaries. A list of fossils is given, 74 species. [Are not these post-pleiocene ?]

Sir Richard Griffith, Presidential Address to the Geol. Soc., Dublin, 1836. *Jour. Geol. Soc. Dub.*, vol. i. p. 151.

Prof. Oldham, On the more recent Geological Deposits of Ireland. *Jour. Geol. Soc. Dub.*, iii. p. 61 and 131. [Important paper containing localities of shells in the drift all over Ireland. (Study this carefully.)]

Du Noyer, Remarks on the Geological Sections Exposed by the Cuttings on the Dublin and Drogheda Railway. *Jour. Geol. Soc. Dub.*, iii. 255.

Near Malahide are striæ east and west or N. 70° W., and boulder clay containing pebbles of altered chalk, flint, limestone, granite and syenite, greenstone, schist, &c. At Skerries Station is an 'esker' made of limestone gravel, and this is overlaid by a calcareous clay,[1] containing sea-shells of species now living. At the River Delim (at the north boundary of Co. Dublin) is sand and gravel with calcareous clay[2] on top, containing fragments of recent sea-shells; farther north fishbones are numerous in the drift.

---

[1] Raised beach probably.

[2] Raised beach.

Oldham, On the Drift Deposits of the County Wicklow. *Jour. Geol. Soc. Dub.*, iii. 302.

These marl and clay deposits made in a quiet sea, and containing perfectly preserved shells, cover a large area, and should not be called drift. The great boulder deposit of Wicklow is perfectly distinct from these, and is 'in all cases subsequent to' them. Sea-shells occur up to 600 feet; mountain limestone gravel occurs much higher.

Three Rock and Two Rock Mountains

[With Professor Hull and Mr. Close I ascended the side of Three Rock Mountain to Tickrock village.

At 1,050 feet is till made of granite débris mainly, with carboniferous chert, flint, greenstone, &c. These boulders are scratched.

At 1,200 feet is true moraine material, with huge granite boulders, silurian grit, and carboniferous chert; the granite making the largest boulders, the silurian grit pebbles predominating, and the limestone being very scarce. There is also quartz porphyry, old red conglomerate silurian porphyry (from Navan or Drogheda ?).

At 1,300 feet is till with scratched silurian boulders, much granite, and some chalk flint, also black limestone. Near Calbeck Castle is a stratified deposit of kame-like stuff, containing a few fragments of shells, some flint, many boulders of granite and limestone, silurian grit, &c. Two symmetrical mounds of subangular coarse gravel occur here, full of limestone fragments. There is very little rounding of the pebbles, and it is clearly not a sea-beach.[1]

---

[1] A study of gravels in the south of England shows that the truly marine gravels are well rolled, while ancient river gravel may contain angular fragments. Whitaker (*Quart. Jour. Geol. Soc.*, 1870, p. 551) remarks that it is 'unusual to find angular gravel of thoroughly marine type'; and Codrington (*Quart. Jour. Geol. Soc.*, 1870, p. 528), in an excellent paper on the Gravel of the South Coast, shows that the high-level gravels

This is about 1,200 feet. Some of the drift is compacted by lime into a veritable conglomerate or breccia. Chert abounds. It is clearly a re-sorted moraine material, and striæ are still seen on many fragments and pebbles. Ther is often no trace of rolling.

(Kinahan, according to Close, is mistaken in describin marine drift on top of Canakmarine, near Cahirsiveen, a 2,000 feet. It is only local stuff, as Close observed.) Th drift makes fertile soil, and the edge is clearly define between the cultivated and uncultivated land. We ascende off the drift and were above it at 1,250 feet.

On Two Rock Mountain at 1,650 feet I found a boulde 1 foot long of dark gritstone, probably silurian, certainl foreign. This is like the single limestone boulder on top o the Kittatinny Mountain, Pennyslvania. The top of th ice was almost free from stones, as Nordenskjold observe in Greenland. All the mountain top is covered by decomposed granite 'grus' on which is peat and heather.

Mr. Close agreed with me that the deposit with shell lately described is re-sorted moraine stuff, but Professo Hull insisted that it was in no sense glacial, but marine although, the stratification being confused and irregular, h admitted that it was re-sorted by landslips or otherwise.

On the summit of the mountain, at the sepulchra mound at 1,760 feet, are fragments of foreign sandstone Mr. Close has found several such here, viz. white sandston from perhaps the coal measures. (Conglomerate occurs a Dunabato to the north.)

We found a small sharp fragment of limestone on th

---

at 420 feet, with angular flints, are due to ancient pre-glacial rivers inlets. Sir Charles Lyell thought they might be due to the sudden meltin of snow. The true marine gravel with shells found at lower levels is mo rounded.

Cross-bedded structure is characteristic of river gravel and of torrenti action; it occurs in the Delaware River at Trenton. Also in the vall gravel of the Isle of Wight (*Quart. Jour. Geol. Soc.*, 1870, p. 539), in bo cases with mammalian remains. I have not touched upon this subject.

very summit, close to the mound. The granite on top had quite the appearance of being glaciated, though it was so decomposed that we could not be certain. We saw also a boulder of crystalline greenstone (?), diabase or gabbro. We found many boulders and sharp fragments of silurian grit, and other sandstones, &c., on the north side of the top, at 1,740 feet.

We descended to Ballyedwardaff, to 1,075 feet, where are mounds of drift. These are opened in parts where rudely stratified for gravel pits. The strata are inclined in one place 55°, like kame-stuff. The gravel is subangular, many of the fragments being sharp; it also contains limestone fragments, large boulders of granite, small pebbles of chalk flint and minute pieces of hardened chalk, silurian grit, &c., together with sandstones. Many of these boulders are of a typical glacial shape. It is clearly a re-sorted morainic material, and has no resemblance to a sea-shore or sea-bottom deposit. Boulders of greenstone porphyry are abundant. I found a pebble of white chalk and some minute fragments of shells here also. Afterward I found chalk abundantly in pebbles of different sizes, up to four inches in diameter. The mass of the drift is made of granite 'grus,' and the most numerous pebbles are limestone. There are no bands of shells, sorted out in lines by their specific gravity, such as is the case on sea-shores and in marine deposits. There is, on the other hand, evidence of torrential action, such as sub-glacial rivers or torrents issuing from the end of an ice-sheet might make.

At a second gravel pit at 1,000 feet slightly farther north, are shell fragments, numerous limestone boulders, sometimes finely glaciated, and flint, greenstone, porphyry, sandstone, granite, &c.

The whole deposit forms a kame-like ridge, which runs northward down the little valley. It is like my 'marginal kame,' and has no aspect whatever of being the remains of a sea-beach. There are no terraces or constant levels, as with ordinary marine gravel. It is quite unlike the Bryn

Mawr gravel of Pennsylvania or the high-level gravel of the south of England.

Mr. Close told me that he found on examination that the statement made by Kinahan in the 'Explanations' that marine drift occurs at 2,000 feet, near Cahirsiveen, is incorrect, local detritus alone occurring there. He told me that a moraine-like mass of drift occurs at the watershed of Ballybrack Valley (Glencullen), south of Two Rock Mountain, and that another moraine-like mass observed by Agassiz (*Proc. Irish Acad.* 1857), occurs up the valley in which the Dodder flows. This is not due to a local glacier, as Agassiz thought, but to the central ice-sheet, as it is full of limestone boulders. The moraine is near the letter A in the word CRUAGH on the Ordnance map.[1]

(N.B. Compare with remarks on the Lancashire district.)]

Bray

[With Professor V. Ball I went to Bray, and walked around Bray Head, some two and a half miles south of the town.

Just south of the point of Bray Head are striæ which point directly towards Lambay Island.

Farther south on the southern extremity around the head and in view of Greystones are excellent striæ on a flat surface, which point to Howth.

Just south of this are large accumulations of drift. Till is well exposed in a railway cutting, and makes cliffs on the sea. This till contains striated fragments of limestone, granite, &c., and small pebbles of chalk flint, and marine shells. It is partly stratified.

---

[1] I conclude that just before the time of maximum glaciation, while the glaciers were becoming confluent and advancing, there was a period of marine submergence of some 400 feet, more or less, causing an amelioration of the climate. Marine shells were then deposited in sands and clays, in an estuary extending from Dublin to a point some miles west, and up to the base of the mountain at Bohernabreena. The glacier then advanced, ploughed up, and for the most part obliterated the marine sands, yet carried some of the shell fragments on its front edge higher up on the mountains.

The shells have been apparently pushed out of the sea and are in small rounded fragments.]

NOTE ON A KAME

[This kame has a well-defined shape and consists of rounded hummocks joined by a ridge. A road runs along the top of the kame for two miles.

It is in parts, especially below, often very sandy. Coarse layers lie on and alternate with the sand, and false bedding and inclined strata occur on a large scale. The pebbles and boulders are all well rounded, and are thus quite different from the subangular deposits of Two Rock Mountain. They are much more waterworn. Limestone pebbles form the main ingredient, but sandstone conglomerate, chalk flint, and chalk are also common. Granite is absent, and the deposit has clearly not come from the mountains south of here.

It seems to be due to a sub-glacial or terminal stream flowing south toward the mountains and into the valley of the Dodder. The kame stops at the Dodder, and its materials are all from the north.

The banks of deep till exposed on the Dodder show that the till has the same composition, mainly limestone, and no granite. There are no shells in either the kame or the till. On top of the till at the River Dodder is terrassée drift full of granite pebbles. This lies on the till, and is stratified and of lighter colour, and has clearly been washed down from the mountains past Bohernabreena. Probably any shells that have been in the kame are ground up, while they exist at Bohernabreena because that deposit is less waterworn. The kame is clearly not a sand bar, and shows no marine characters.

Lydian stone is common in the limestone.]

Howth

[With Mr. McHenry, of the Geol. Survey, I go to Howth. Striæ are on the dolomite on the Sutton shore. They run magnetic N. 43° W., i.e. true N. 64° W. (the variation being 21° W., add 21° W. to reading).

On top of this is a good section of a raised beach, in which the stones lie in bands, with a quantity of shells. The stones lie flat with the shells, thus:

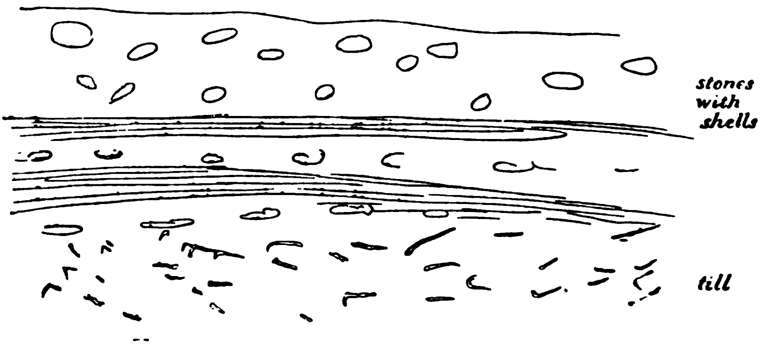


FIG. 24.—Bands of Stones and Shells on Till Raised Beach (Howth).

There are many shells, broken and whole, often delicate, though lying among large stones. The parallelism of layers is constant. A side view shows this raised beach to be made of large stones, which lie on a till made of smaller stones. Delicate shells lie among the large boulders.

We go to the north side of the island near Howth Lodge, where is a good artificial exposure of limestone till, in which are no shells, overlaid by a marine deposit, consisting of a loamy or alluvial deposit, full of marine shells, in fragments or whole, but not rolled. There is gravelly loam on the top.

The shells are solen, fusus, littorina, patella, &c., &c.

The top of this 'raised beach' is about 30 feet above the sea.

Probably it is the same deposit which contains shells on the railway from Dublin to Drogheda.

Mr. McHenry says the raised beaches in Co. Antrim go up to 75 feet, and are proved by shells, by caves, and by pillars, &c., &c.

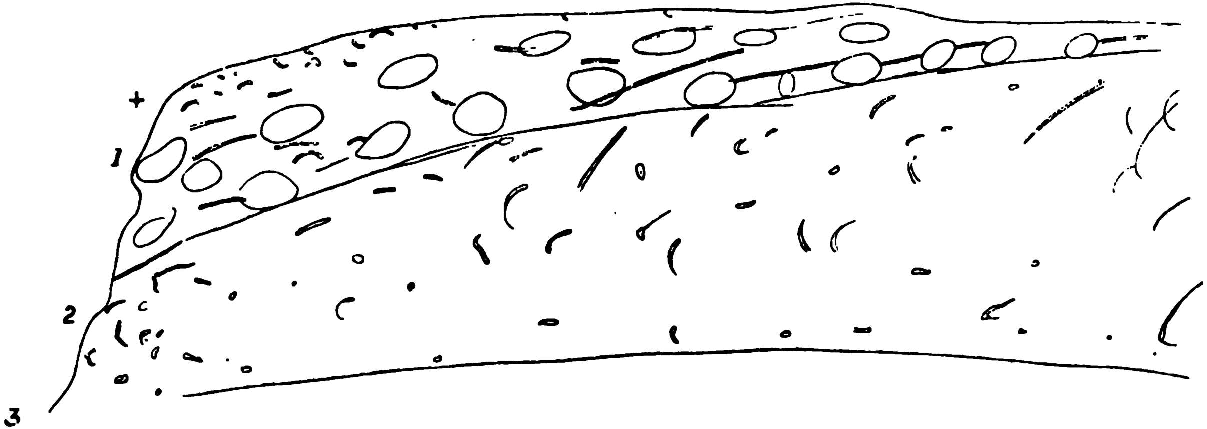


FIG. 25.—Section of Raised Beach with Bands of Stones and Shells on Till (Howth).

+, fresh-water loam with helices; 1, large smoothed stones, more or less flat, with numerous shells, particularly at the bottom of this deposit; 2, till made largely of limestone; 3, striated rock (striæ go E.S.E.). The shells are fusus, littorina, littorea, cardium edule, mytilus edulis, patella vulgatum, buccinum, littorina litoralis, astrea edule; these are fragmentary, but not rolled shells; also cyprina. On top of the raised beach is a layer of fresh-water shells in loam; among these is a helix which is perfect and not fragmentary).

We go to Balskaddin Bay, on the east side of Howth Harbour, where is striated limestone, on which lies a tough limestone till, very black, and full of finely striated boulders, mainly limestone, over which deposit is a stratified and sandy drift.

The till contains a few shell pebbles, also very well rounded, and perhaps striated shell fragments, all being parts of hard shells. There are no whole shells. These glaciated shell fragments lie in the true till along with scratched boulders, and have been actually pushed up out of the sea.

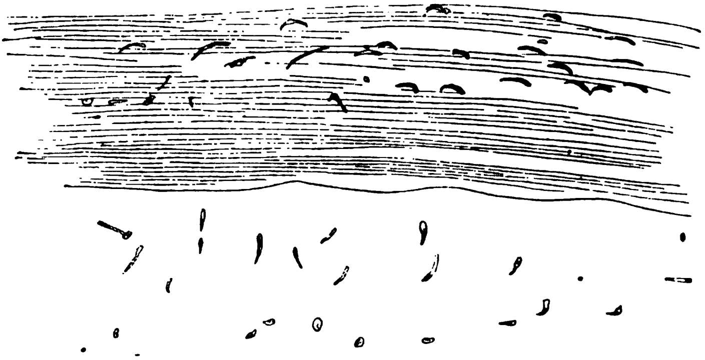


FIG. 26.—Artificial Section. Limestone Till, north side Howth Island.

The stratified sand and gravel also contain numerous rounded shell fragments. These are quite unlike those in the raised beach, being all more or less rolled. This deposit is not horizontally stratified or loamy, as was the raised beach, but is often cross-bedded.

We ascend the hill, where are fine sections on the road of stratified drift, rising to perhaps 150 feet. This shows false bedding, and contains numerous shell fragments, and sometimes whole shells. Among the pebbles are chalk flint, tourmaline, granite, greenstone, diorite, &c.

The shell fragments are so very abundant—more than elsewhere inland—and the deposit so sandy, that we here have, I think, the sea sand and its shells bodily moved into the land.

The shells become less and less frequent as we go inland, and are exceedingly scarce on Two Rock Mountain. This is in accordance with the theory that they were pushed out of the sea. If this were a marine deposit, shells would be more frequent on the beach. But they are not; and, as I formerly showed, the Two Rock deposit is not a beach deposit, but a re-sorted moraine. The stones here are more rounded, and there is more sand than on Two Rock Mountain. The ridge of drift does not surround Howth peninsula like a terrace, but is a ridge running toward the sea, kame-like rather than terrace-like.

Among the shells collected are numerous rolled fragments of Cyp. islandica, a large hard shell, and only two nearly complete shells—an astarte and a turritella—the rest being much rolled. The shells in the till are of much interest, as showing the ice moving off the sea, as at Liverpool and on the coast of Lancashire.]

Co. Wexford. Abstracts. Striæ. Abstracts Expl. 158, 159, p. 19.

Striæ in Co. Wexford :—

(1) Newtown, near the boundary of Slein Bann, N. 20° E. going SS.W.

(2) Cherry Orchard, N. 5° E. going south to west side of Slaney Valley.

(3) Blackstoop, N. 15° W. going south on the west bank of the Slaney.

In Expl. 169, 170, 180, 181, p. 13.

(4) In Ballycormick, Co. Wexford (sheet 42–6) near the old castle, striæ are N. 45° W., N. 5° W., and N. 10° E. Mean.

(5) In the north-west part of Forth Commons striæ are N. 10° E. (sheet 42) [slickensides].

(6) South-west of Newbay, north-west and south-east. (P. 13. There is a quantity of chalk in the drift. It is marine drift, and the chalk, perhaps from Antrim or

England, is much more abundant than farther north. The oldest drift goes up to 300 feet above the sea.)

Dublin to Arklow and Shillelagh

[After passing the heaped-up drift deposits south of Bray Head, the country adjoining the sea is flat; though behind Greystones are hummocks of drift, and rounded hummocks and low ridges of stratified drift are seen just south of here. A flat boggy country follows, extending to Wicklow. At Wicklow Station hills of false-bedded sand and gravel are well exposed, which are heaped up just beyond into large moraine-like ridges.

The country to the west is glaciated from west to east (see Hull, *Geol. of Ireland*, and Close, *Glaciation of Dublin*). We here turn inland. There are masses of till about Glenealy, and Carrick Hill, close by, is glaciated on top. One mile beyond Glenealy on the railway is an apparently glaciated surface of slate. The region about Rathdrum seems to be heavily glaciated, but I notice no drift. I see no drift till we reach Avoca, where boulders are numerous, bordering the river valley. There is boulder drift also at Wooden Bridge. I go from there to Timoleague, and after passing through an unglaciated (post-glacial) gorge suddenly enter a drift-covered country. Much drift, filled with large boulders, covers the country at Aughrim. Granite boulders abound. Long ridges of drift here run parallel to the railway. The stream meanders in a drift-filled plain, and an ice-sheet was clearly here. There is a peat bog, clearly once a lake, before reaching Tinahely. Deep drift with granite and quartzite boulders occurs at this place, and at the station is a deposit of stratified drift.

At Shillelagh I drove five miles across the hills in the area of metamorphic silurian slate, and to the edge of the granite on the road towards Tullow. Everywhere in the valleys and on the hills are abundant boulders of granite, often of large size, and well glaciated. Smaller boulders of fossiliferous carboniferous limestone are also common in the fields and on the walls, which were clearly transported by the ice-sheet from the west. The nearest limestone is about Carlow, fourteen miles further west. The ice-sheet certainly came thus far east, for there were no mountains west of Shillelagh to intercept it. It is probable that the ice-sheet filtered through even the higher mountains to the north. The greater part of the limestone was combed out west of this locality, and the stippling on the Geol. map, sheet 138, represents the deposits, which consist mainly of limestone gravel, and appear in force some four miles west of Shillelagh.

(Did the ridge of hills to the east prevent the ice-sheet from reaching the coast?)

On the Geol. map accumulations of limestone drift are noted about Hackettstown, Clonmare, and at the edge of the granite area in the middle of the bottom line on the map.

I collected specimens of metamorphic lower silurian (Llandeilo and Bala beds) schist in the granite contact zone.

I go to Arklow viâ Wooden Bridge. After passing the rocky boulder drift heaped up about Aughrim, I see no more all the way to Arklow. Is this the moraine?]

Arklow to Gorey

[At Arklow I walk to a quarry of shale, and see no trace of drift and no smoothing of the slates on top. The boulders used for paving the Arklow Road have been brought from the river-bed. I go to the eruptive rocks at Arklow Head, two miles south of the town.

On the way I pass a quarry of shale, and see no till, but a loam containing some pebbles lies on top of the smoothed off shales, as if here by the action of water. This is only 100 feet above the sea. The pebbles are all local here, but at the next opening some large rounded boulders of granite occur, and the deposit looks more like till.

At Arklow Head Quarry glacial striæ cover the surface of the rock, viz. (magnetic) N. 65° W. (poor), E. and W., N. 80° W., S. 83° W. (good), E. and W., N. 85° W.[1]

Large flat boulders of granite, sometimes finely striated, are imbedded in the till overlying the rock. I found also a pebble of chalk in the till.

Glacial striæ occur here on top of the head going northwest.

I drive to Gorey and see no decided signs of glaciation.[2] The glaciation seems to have been weak here. No great ridges of drift, no perched erratics, no distinct roches moutonnées, no kames, are seen. The ice may possibly have been thin? At Gorey Station is an exposure of coarse stratified drift, in which the pebbles are mainly shale, but granite and even chalk flint occur. Are the chalk flints in the drift derived from an old pre-glacial marine deposit?

I take the train for Wexford. Large banks of the same drift are penetrated farther south, and we are clearly entering now a region deeply covered by drift. Is this because we are getting away from the shadow of the mountains? We pass through many banks of stratified gravelly drift about Ferns. (It grows too dark to see beyond here.)]

Wexford and Vicinity

[I drive toward Forth Mountain (776 feet) from Wexford. At 200 feet are cuttings for brick clay and large deposits of stratified sand lie under the brick clay. The clay at Jones' brickyard is about 4 feet deep, lying on sand, which is 20 feet deep. The sand is irregular, and contains gravel. Among the boulders in the clay are granite, sandstone, shale, &c., and occasionally pebbles of chalk flint. Chalk flint is not uncommon in the sand. All this is glacial.

'Marl' lies below the clay in a field behind the road. This is blue and entirely different and older than the drift deposits. Perhaps the clay is in part re-made out of the

---

[1] Magnetic east and west equals S. 69° W. or N. 69° E.

[2] Near Inch Station I drove through a ravine, said to be the lowest place in Ireland, and below the level of the sea.

'marl,' elevation, 200 feet. It all looks like water-carried drift. I go to Forth Mountain, and see there no drift whatever. The rock is not glaciated, and no erratics or drift are noticed.

At 700 feet is a fine view in all directions, but no trace of drift or glaciation is in sight. I find slickensides pointing N. 10° E., and believe that they have been mistaken for glacial striæ. We are out of the glaciated area. The rock is a rough schistose quartz sandstone like the Potsdam sandstone of Pennsylvania. It stands out in jagged non-glaciated crags.

On descending the mountain the first rounded stones I see in the walls are at 375 feet. At 350 feet, at a point one mile and a half west of the town, sand and gravel hills are heaped up. The gravel and sand are false-bedded, and contain many pebbles of black limestone, also granite, chalk flint, and greenstone. The boulders of limestone are abundant, and the flints are larger and more frequent than about Dublin. In the bottom of the pit is a true sand resembling a sea sand containing many fragments of marine shells. This sand is clean and full of rounded quartz grains, so that I at once recognise it as sea sand. It is full of fragments of shells, also chalk flints, &c. The limestone must have come from either the north-east or the south-east of this point. The Wexford drift seems to be aqueous; the brickclay corresponds to the Philadelphia brickclay, and the gravels to those of the London region.

I now take the train for Rosslare Harbour and Ballygorey. It is all low ground, which is covered by sand and gravelly clay. These aqueous deposits lie on the rock just as they do near the Delaware River. Sharp fragments of the local Cambrian sandstone and quartzite lie in these gravelly deposits, but no glaciated stones are seen. Alluvial flats occur farther on (like those of the League Island area[1]) succeeded by a terrace made of gravelly loam, and a blue clay at Rosslare, is like the brickclay of South Broad Street, Philadelphia. It contains numerous pebbles of syenite, &c.

---

[1] Near Philadelphia.

At Ballygorey (Rosslare Harbour) is the same deposit. Here on the sea shore are cliffs of extremely tough bluish gray clay [1] breaking in columns.

It is so tough that the waves roll it into round boulders, which lie on the beach exactly like stone boulders. A dyke of greenstone outcrops here. Large boulders of this also occur on the beach, and are often polished and striated as if by glacial action. Striated boulders of red sandstone are likewise seen. Is this shore ice or what? Shell fragments abound in the clay. These are often quite sharp, and among them are delicate shells like the shells in the raised beach at Howth. The tough clay lies directly on irregular jagged granite, flint, and greenstone, and contains beautifully glaciated stones of dark greenstone. Very finely glaciated boulders also lie upon the beach. In fact, the most beautifully glaciated boulders I have ever seen anywhere may be seen here lying at the foot of these clay cliffs, having clearly fallen out of them. Yet this is a non-glaciated area. The underlying rock is not glaciated, and the tough clay is evidently marine, and made at a time of submergence. I am now convinced of what I suspected some time ago, that the most beautifully glaciated stones are to be found in tough clays of aqueous origin.[1]

---

[1] This tough clay, like other tough 'boulder clay' in middle England, is very different from the stony, sandy, dirty, heterogeneous dumpheaps of drift formed by a land glacier, and to which I am accustomed to restrict the word 'till.' Most 'boulder clays,' properly so-called, are of aqueous origin, formed in water, into which sub-glacial streams flowed. The formation of this deposit is clearly described by R. Brown in a paper on the 'Physics of Arctic Ice' (*Quart. Jour. Geol. Soc.*, 1870, p. 682), where he describes how sub-glacial rivers in Greenland, charged with suspended mud, enter the sea, discolouring the water for miles, and finally depositing an impalpable powder to form a clay, of which he says: 'I can find no appreciable difference between it and the brickclay or fossiliferous boulder clay. In this clayey bed,' he adds, 'the Arctic mollusca and other marine animals find a congenial home and burrow into it in great numbers' (l. c.). The 'laminated boulder clays' of Scotland must be of similar origin, also the clays lying south of Lake Erie, and the lower boulder clay of Lancashire. (*Quart. Jour. Geol. Soc.*, 1870, p. 644).

The upper and lower boulder clay of Lancashire in the lowlands is also a marine (?) deposit, containing shells. 'Marl' with glaciated stones occurs at the base of the so-called upper boulder clay. The boulder clay does not vary in character with the underlying beds as true till does, but is of uniform character like the Wexford clays. There was a submergence in Lancashire of 150 feet ±. (See a good paper by De Rance, *Quart. Jour. Geol. Soc.*, 1870, p. 649.)

The Norfolk and Cromer clays contain glaciated stones, as does the York clay, and the clay near Bolton Abbey, all of which are outside the glaciated area. The shells in this clay are often delicate and unrolled. Because there has been no attrition the shells are preserved, and the stones retain their most delicate striæ. The stones have been dropped from floating cakes of ice or icebergs into a mud at the bottom of a quiet sea. The stones in genuine till are not so finely striated as a rule, and it is often difficult to find a striated stone. This is because of the rough treatment to which they have been subjected by the sandy and gravelly waters circulating beneath the glacier. True glacial till is a stony, impure material, quite unlike the tough pure clays devoid of stratification which occur outside of the glaciated area in aqueous deposits.

This clay or Wexford marl is of glacial age, and is perhaps the 'great chalky boulder clay' (?)[2] of Norfolk. It contains flints of a black colour quite unlike the Antrim flints. It is not a pleiocene deposit. It and the accompanying sands imply a submergence of nearly 400 feet, thus corresponding with the submergence in Eastern and Southern England.[1]

---

[1] In many parts of England south of the glaciated area scratched stones occur when imbedded in a stiff clay. Thus at Rugby 'well-striated' blocks of liassic limestone, chalk, and flint occur in a clay which is a reformation of lias clay. (Wilson, 'On the Surface Deposits in the Neighbourhood of Rugby.' *Quart. Journ. Geol. Soc.*, 1870, p. 193.)

[2] Or the 'Hessle clay,' or the 'purple clay.'

Large boulders of porphyritic granite like Shap or Galway granite occur here. The fact that the chalk flints are much larger and more numerous here than at Dublin or Howth shows that they did not come from Antrim.

The boulders of clay are curious here; I have never seen the like elsewhere. Sometimes stones and shells are imbedded in them. The clay forms a horizontal deposit and a level country. The flints at Whitney Bay and Youghal belong to this same deposit.

As there is no such deposit as this at Glengarriff, where the rocks are striated down to the sea-level, or in Donegal or near Dublin; or, in fact, anywhere in the glaciated areas of England or Ireland, it is clear that the submergence of 400 feet was not posterior to the time of maximum (the last) glaciation. Further, as glaciated erratics lie in the clay, it is also clear that the submergence did not occur in an inter-glacial epoch. I believe the submergence to have taken place at the time or before the time of maximum glaciation.

The flints in it and its associated sands are apparently English, not Antrim (Irish), in origin, and the whole deposit seems to me to indicate a submergence of 350 feet during the time of maximum glaciation elsewhere. I found no signs of glaciation (i.e. of land-ice) about Wexford or east of Forth Mountain, and the region appears to correspond, glacially speaking, with central England during the ice age.

---

[1] Chalk flints also abound in a gravel in South Wales, between Cardiff and Pendoylan. On the sides of Ely Valley chalk flints occur up to 400 feet, indicating a similar submergence to that in Ireland. The chalk-bearing gravel underlies the boulder clay or true glacial till, as in Ireland. The till sometimes contains chalk flints, taken up from the underlying deposit, as was the case in Wexford. (J. W. E. David, 'Glacial Action in South Brecknockshire and East Glamorganshire,' *Quart. Jour. Geol. Soc.*, 1883, p. 45.)

If the marine submergence occurred before the maximum glaciation, then the Dublin plain would have had marine gravels containing shells west as well as east of the Wicklow Mountains; for as the ice advanced, it pushed these deposits up on to the mountain. So in Wales. The clay and valley shell-bearing drift is marine. In *Explanation*, 169, 170, 180, 181, by Kinahan, we read that the fossiliferous drifts of Wexford are marine, and were made at times when the sea was at different heights. The oldest drift was made when the sea was 280 feet high, the second when at 100 feet, and the third when at 25 feet. The highest sea he erroneously calls the 'esker sea,' but this sea made no eskers, for there are none in the region (p. 13). Flints get more numerous and larger as we go southward, and are clearly due to chalk in the Irish Channel. A remnant of it still remains in Cornwall, and there is more at Antrim. Professor Hull agrees with me that the marl was not made by an 'esker sea,' the eskers being younger. Sir H. James is mistaken in thinking the sea rose to 500 feet (p. 29). The marl contains glaciated stones at Greenore (p. 36). He is mistaken (p. 37) in thinking that these stones are the waste of older glacial drift, for in that case the striæ would not be so perfectly preserved. Glauconitic green sand like that with English chalk occurs near Kilmore Pier (p. 43). A large block of Carnsore granite has been drifted westward to the neighbourhood of Kilmore Pier (p. 45). This with the westward drift of the chalk shows marine action pushing the boulders inland.

At Carnsore Point there is drift full of angular blocks, resembling true morainic till somewhat, except that it rests upon rocks, 'which show no trace of ice action,' and that it is interstratified with sands, gravels, and marl, which contain shells and chalk flints (p. 50). Clearly Mr. Kinahan is right in considering these drifts marine. The glacier was in the sea. Except that the sea here was open to the south, the deposits may be compared with those of the Lincolnshire and Cromer coasts. In the latter case the sea was enclosed by land on the south and by ice on the north, and the water was more fresh than salt. The shells also in the latter case prove that the conditions were glacial estuarine, while at Wexford they were oceanic, and the ocean was warm; still warmer at St. Erth. (*Quart. Jour. Geol. Soc.*, 1886.) The same 280 feet submergence occurred in South Wales. (*Quart. Jour. Geol. Soc.*)

The cause of climatic changes is necessarily long anterior to its effect. I believe that the submergence, followed by the warm climate which caused the glacier to retreat, must have been before rather than after the time of maximum glaciation. The period of maximum glaciation was by no means the period of maximum cold. On the other hand it was probably a period warmer than at present. A depression of 400 feet would necessarily cause a warm climate, and Prof. Whitney in his climatic changes has adduced many proofs that since that time the climate has been gradually growing colder.

That submergence really produces a warm climate is proved by the fauna and flora of a past geological epoch.

During tertiary times the land was submerged in Great Britain and America up to nearly 500 feet, and the fauna and flora are clearly of a warmer period than the present. Thus Greenland and Spitzbergen, as Heer has shown, enjoyed a temperate climate. In the Palæozoic age corals abounded all over the Northern Hemisphere, which was then submerged deeply. But in the carboniferous age, one essentially of much dry land, the climate was colder, and we have evidence of floating ice-cakes.

Thus the cold which caused the glaciers was due to a pre-glacial elevation, as is proved by pre-glacial sunken river valleys. Abundant water was supplied to the advancing glaciers by the submergence which followed, whose culmination may have been somewhat before the maximum of glaciation. As the glacier retreated the sea followed it rearranging the drift in the lowlands (?), depositing clays; carrying boulders dropped from the icebergs, and sands containing shells (?) as in the Lancashire lowlands.]

Wexford to Waterford,
viâ Ballywilliam and New Ross

[No trace of glaciation is seen between Wexford and Killurin. At Killurin the absence of glaciation is clear; but just beyond the station is a kame-like hill of gravel, with excellent cross-stratification, and a little farther on coarse gravel occurs in large quantity. At Macmine Junction there is drift, consisting of a blue clay, some sandy layers, and a loamy, gravelly deposit, containing sharp fragments of the broken underlying shale, with pebbles of granite, &c. It seems to be clearly an aqueous deposit belonging to the 'Wexford marl' series. Fragments of the underlying shale are mingled with the deposit, just as the decomposed gneiss at Philadelphia is mixed with the gravel over it. The pebbles as a rule are small, though large boulders are occasionally seen. The underlying shale is not glaciated. This is at an elevation of only 25 feet ±.

There is no trace of glaciation west of here. At Chapel I see no drift of any kind, not even gravel. The large boulders of eruptive felsite which are common in the fields to the west are due to ordinary weathering. No sign of glaciation could be found at Palace East, where, as at Chapel, weather-broken rocks come to the surface. There are high mountains farther to the north. Just west of Palace East are numerous boulders, like a moraine suddenly appearing. At Ballywilliam boulders of granite abound. I drive to New Ross. The walls on either side of the road are made almost entirely of granite erratics, sometimes glaciated; although the underlying rock as shown on the banks of the Barrow is shale. We have entered the glaciated area. A great bank of till, full of glaciated erratics, is well exposed, 40 feet deep, at the junction of the Barrow and Pill Island. No glaciation is seen on the slates.]

Waterford

[Signs of glaciation are here very faint. The rock is only slightly glaciated. It is a great contrast to the bed of a local glacier or to the Donegal and Galway regions.

Striæ on the Waterford, Dungarvan, and Lismore Railway half a mile, or at the first bridge, north-west of the station, on old red sandstone, go (magnetic) S. 17° E., S. 15° E.; mean, S. 16° E. This is true S. 37° E. Erratics are scarce, and the glacier was apparently thin and combed out here.]

Carrick-on-Suir to Rathgormuck

[We drive six miles south-west from Carrick to Rathgormuck, finding ample evidence of glaciation the whole way. Boulders of red sandstone and conglomerate are strewn thickly over this district of silurian shale. Rock rarely appears, drift covering it entirely. It is a high platform, extending to the base of the Commeragh Mountains. The general elevation is 400 feet, points rising to 600 feet. We go to Ross Bridge, and return by the Carrick and Dungarvan road. The ice-sheet clearly abutted against the north side of the Commeragh Mountains, and the drift is banked up against Knockanaffrin, &c. The tops of the mountains are jagged, and supported local glaciers. The elevations of these mountains are 2,181, 2,478, 2,028, 2,428, 2,308, 2,597, 2,335, 2,445, 2,340, 2,180 feet, &c.

They show signs of glaciation on their north east side, as high as 1,000 feet, up to which height they are rounded off, and drift occurs. Above this they are jagged and contain cwms, glacial lakes, and other evidences of local small glaciers. Ten small 'loughs' are marked on sheet 167.]

Waterford to Ballyculláne and Taylorstown

[From Waterford to Passage is deep drift. It is true till, and encloses bogs in many places. There is heavy glaciation here. Near Mount Druid I find greenstone ash, a green shale.

We cross to Ballybrack and see deep drift and many boulders on the road between there and Burkestown, on lower silurian shale. About Ballycullane is much drift, also numerous boulders of granite, granitic gneiss, felsite, &c.

Granite is plentiful in the drift at Taylorstown Bridge. No glaciated rock surfaces are seen. Returning by a more southern road to Ballybrack, drift is not so abundant.]

Striæ in Co. Wexford

Mr. Kinahan having kindly lent me his MS. striæ maps on sheet 169 I plotted his two supposed localities. On the Index map I put the other striæ.

On sheet 149 striæ are indicated at Tara Hill going east (no exact observation). The supposed ice-motion is only four miles north of Rimchapel, and striæ are marked at three miles south of Rimcastle on the coast. On the coast four miles north of Rimchapel they are marked N. 20° E. toward the south.

On sheet 148 striæ are:—

1. Ballingate House, N. 25° W.
2. N. 45° W. outside boundary.
3. On the River Bann, south and east of Ferns. One mile south, N. 20° E.
4. Two miles south, N. 45° E.
5. Two miles south-east, roches moutonnées.
6. Near junction of the River Bann and River Slaney. N. 65° E.

On sheet 139:

1. Three miles west of Mizen Head. N. 60° W. and N. 35° W.
2. On Ovoca River, one mile south of Castle Howard. N. 40° W.
3. One mile north of Aughrim River. N. 65° W.
4. On Aughrim River, one mile north-west of Wooden Bridge. N. 65° W.

ENGLAND

3. GLACIATION OF DURHAM AND PART OF NORTHUMBERLAND

References

H. Miller, On Tynedale Escarpments. *Natural History Transactions of Northumberland, Durham, and Newcastle-on-Tyne*, vii. 1880.

For direction of glaciation, *v.* Thompson; York Meeting British Association.

R. Howse and J. W. Kirkby, Synopsis of the Geology of Durham and Part of Northumberland. *Tyneside Naturalists' Club*, 1863.

Striæ occur at Ryhope Snook. Good exposures of drift occur at Hendon, and at Blue House, south of Sunderland. Sections of drift are at the mouth of the Tyne, on the north side, east of Bar Light (10 minutes' walk from Tynemouth Station).

N. Wood and E. F. Boyd, On a 'Wash' or 'Drift' through a Portion of the Coalfield of Durham. *North of England Institute of Mining Engineers.* Vol. xiii. 1863–4, p. 69.

Contains a map of the course of the so-called 'Wash' from Newcastle to Durham. It is a mass of gravel filling an old river valley, sometimes, as at Durham, kame-like in contour. It follows and connects the valleys of the Team and the Wear, and many vertical sections of this drift-filled ancient valley are given. The paper speaks of the difficulty of accounting for the peculiar passage of the river through the solid rock at the city of Durham, instead of going directly along the valley filled with the 'Wash.' The large sand hills west of Durham are mentioned. This drift is 84 feet deep at Crossgate Foundry, and is well shown in the railway cutting of the Bishop Auckland Railway at Redhills. As shown by borings, it is 150 feet deep in Bear Park, and 222 feet deep at Lanchester Valley.

R. Howse, The Glaciation of the Counties of Durham and Northumberland. *North of England Institute of Mining Engineers.* Vol. xiii. 1863-4, p. 170.

Striæ and drift at Fron Rocks, near South Shields, are described. The striæ are on limestone, and go north, north-east, and east, the ice, according to the author, going from the west to lower ground, and the boulders being derived from the Pennine Chain and the east coast. Cheviot porphyry, granite, &c., occur as boulders, and many striated boulders were found. The boulder clay is thick between the Cleaton and Fulwell Hills, and occupies the coast-line from the Wear to over a mile beyond Hendon. Here is much magnesian limestone, and apparently more boulders of Cheviot porphyry than there are further north.

Over the boulder clay is a clay and sand often full of *chalk flints*, as near South Shields and Tynemouth. The deposit holding flints is full of sand-beds, and the flints in the drift near Durham are mentioned. These flints are believed to have come from Denmark, as they are of identical character with those found in that country. [Chalk flint also occurs north of Aberdeen.]

The south-east part of the county of Durham is covered by mounds of gravel, rubble, and sand, some of them forming hills of remarkable configuration. Glaciated rocks occur:—

(*a*) Deep furrows are on limestone in a quarry near Belsay, where glaciated boulders also occur. (See Loftus, *Tyneside Transactions*, vol. i. p. 348.)

(*b*) Striæ are on limestone in a quarry on Hawkhill Farm, near the river Aln. The rock is finely glaciated in a north and south direction, exceptional striæ running north-west and south-east. A limestone boulder, striated on its under surface as it lay, showed the direction to be south-east and north-west. (See a paper by Tate, *Tyneside Transactions*, vol. i. p. 348.)

(*c*) Striæ go east at South Shields, while farther west the striæ are north and south.

(*d*) Striæ on the coast near Whitburn go in the direction of the valley.

(*e*) Striæ near Ryhope follow the natural slope of the country.

(*f*) Striæ occur near Tynemouth, Whitley, and Belford.

(*g*) At Ryal are striated surfaces.

G. Tate, Geology of Northumberland and Durham. Newcastle-on-Tyne, 1867. (See *Flora of Northumberland and Durham.*)

Contains a geological map.

Striæ occur (p. 24):—

(*a*) On limestone near Belford at Middleton.

(*b*) On basalt at Farne Island.

(*c*) On limestone at Swinhoe, Dunstanburgh, Little Mill, Hawkhill, Belsay.

(*d*) On sandstone at Birling Carn, south of Alnmouth.

(*e*) On sandstone at the banks of Irthing.

(*f*) On limestone at South Shields.

The abrading agent is stated to have moved in a southerly direction. The boulder clay contains striated erratics, and often overlies a stratified sand.

G. A. Lebour, Outlines of the Geology of Northumberland, 1878, p. 13:—

Many 'kames' are cut through by the North-Eastern Railway between Alnwick and Berwick. Others are in the valley of the Tweed, between Berwick and Carham. A good description is given of the *Bradford kames.* Kames are held to be 'marine deposits.' Kames occur at Chathill, Newham, and Hoppin, and are well developed near Bamborough. (See Tate, *Berwickshire Transactions*, 1866, p. 239.)

Geological Survey Map, sheet 103, south-west, New

Series, sheet 32, drift 1885. Striæ are marked in eleven places about Barnard Castle, viz.:—

(*a*) Just south of Forcett Park, or three miles and three-quarters south of Gainsford, there are striæ on limestone going south-east by east.

(*b*) Two miles south of Barnard Castle, at Timpton Hill (east by south), striæ are on limestone going east by south and east-east by south. Two places.

(*c*) Three miles west of Barnard Castle, on 'Low Crag,' striæ are on the millstone grit, elevation 1,005 feet, going east-north-east and east. Three places.

(*d*) Striæ are in three places, on millstone grit, at 999 feet elevation and 900 feet ±, going east-north-east and east.

They are also at four miles, and at four and a half miles north of Barnard Castle, and two and three miles east of Romaldkirk. [These are all to be considered with reference to the ice-sheet crossing Stainmoor Forest. All are in the western half of the map.]

At one mile south-east of Gilmanby two striæ on limestone go east. Striæ likewise occur near Cleasby, near Darlington, east and west, or according to map E. 17° S.

Also at Stainton, on sandstone, two miles north-east of Barnard Castle, going E. 7° N.

Newcastle-on-Tyne

[Half a mile south of Forest Hall, on the west side of the rails between two bridges crossing the railway, are fine striated surfaces of carboniferous sandstone.

The striæ are very distinctly deepest and broadest at their southern ends, and bear (magnetic) S. 18° E., 20°, 19°, 33°—i.e. S. 20° E. to S. 30° E.

Striæ are also seen on the east side of the rails. Some of the striæ are nearly an inch broader at their southern than at their northern end. The most eastward of the striæ are those highest up on the rock.

At the quarry farther south—Benton Quarry—there is a fine exposure of till, eight feet thick, overlying the sandstone, which shows striæ bearing S. 25° E., S. 30° E. The till is full of striated boulders of trap, limestone, and sandstone. Limestone is quite abundant.

In some places two feet of sand lies underneath six feet of tough, clayey till. Some pebbles of slaty coal were found in it. The till is quite clayey, showing when dry a sort of perpendicular columnar structure. In it are discoloured pockets showing zones of purplish clay. The limestone is fœtid, and sometimes fossiliferous, being carboniferous limestone. A boulder of brittle greenstone (felsite ?) was found ; also some red sandstone.

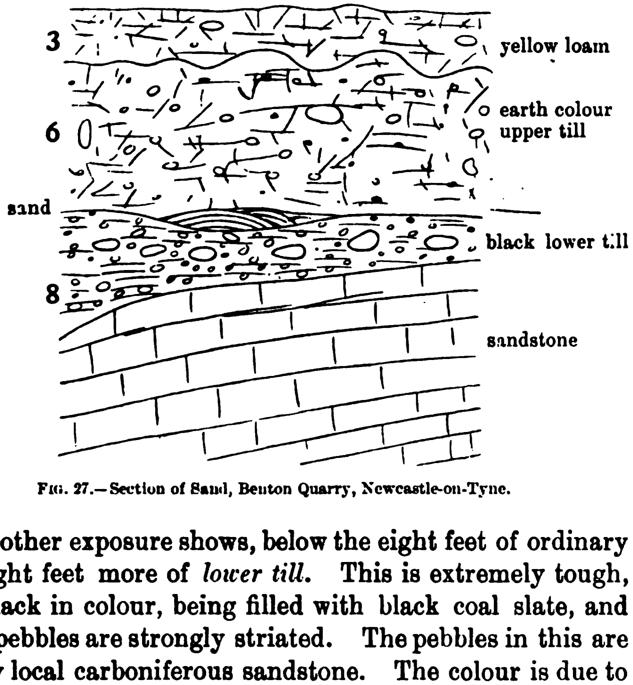


FIG. 27.—Section of Sand, Benton Quarry, Newcastle-on-Tyne.

Another exposure shows, below the eight feet of ordinary till, eight feet more of *lower till.* This is extremely tough, and black in colour, being filled with black coal slate, and all its pebbles are strongly striated. The pebbles in this are largely local carboniferous sandstone. The colour is due to the coal in it, being almost black while wet.

A horizontal line of large boulders occurs in the centre of the black till.

The black lower till is clearly made and *pressed out* by the glacier moving *over it*, the material being more local, more glaciated, and having a sort of horizontal lamination wanting in the upper till. The latter is looser, has more far-travelled boulders, and was *dropped* by the *glacier*. The lower till is much more rarely seen. The sand layer is at the base of the upper till and shows that the ice was melting, or at least that water was flowing below the glacier. This quarry is four to five miles north-north-east of Newcastle. In the railway cutting a quarter of a mile north of the station at Chester-le-Street there is much till and probably some striated surfaces of rock.]

Durham

[At the railway station at Durham there is a high, sharp hill made of stratified kame-drift. The hill is an elongated ridge running north and south. Other ridges, having a similar direction, lie to the north and west, and they exhibit the hummocks characteristic of kames. This is clearly a glacial kame-like deposit.

It contains much sand in parts. The pebbles are rounded, and are mostly sandstone. Among others are many of limestone (carboniferous), still more of felspathic trap or ashes, some small ones of red Scotch granite, and a number of *black chalk flints*. Some of these flint pebbles are six inches or more in length. The flint is nearly black, with lighter spots.

Where did this black flint come from? No Shap granite was found, since Durham is too far north of the Stainmoor Pass.]

Durham to Bishop Auckland and Stockton

[Immediately south of Durham are large hills of drift with moraine-like contours. At Brandon there is a good opening showing till (?). Exposures of till (?) filled with sharp fragments of sandstone occur half a mile north of Willington. This looks like a drift-covered region. Numerous drift hills of characteristic shape are cut through

all the way to Bishop Auckland. At this place there is a deep covering of drift, and many drift hills, and the valley of the river is filled with drift.

At Shildon there are exposures of Permian limestone with little or no till (?). From Darlington to Stockton the land is a level plain. Did the glacier end at Bishop Auckland, or did it end about Danby Wiske, in water ?]

4. *GLACIATION OF YORKSHIRE*

REFERENCES

J. T. CLAY, Observations on the Occurrence of Boulders of Granite and other Crystalline Rocks in the Valley of the Calder, near Halifax : *Proc. Yorks. Geol. Soc.* i. p. 20.

J. T. CLAY, Observations on the Yorkshire Drift and Gravel : *l. c.* i. p. 338.

T. SOPWITH, On the Evidence of the Former Existence of Glaciers in Great Britain : *l. c.* i. 419.

H. C. SORBY, On the Contorted Stratification of the Drift of the Coast of Yorkshire : *l. c.* iii. 220.

W. THORP, On the Diluvial and Gravel Beds of Yorkshire and Nottinghamshire : *l. c.* iii. 224.

D. MACKINTOSH, On the Nature, &c., of the Drift Deposits of the West Riding of Yorkshire, &c. : *l. c.* v. 130.

A. F. PARSONS, The Alluvial Strata of the Lower Ouse Valley : *l. c.* vi. 214.

J. W. DAVIS, On the Source of the Erratic Boulders in the Valley of the River Calder : *l. c.* vii. 141.

G. W. LAMPLUGH, On the Divisions of the Glacial Beds in Filey Bay : vii. 167.

J. R. DAKYNS, On Glacial Deposits North of Bridlington : vii. 123–246.

G. W. LAMPLUGH, On Glacial Sections near Bridlington : vii. 383.

J. E. Clark, On Glacial Sections at York, and their Relation to Later Deposits : vii. 421.

J. R. Dakyns, The Round Boulder Hills of Craven. W. Gomersall: *British Association*, 1873, p. 80. The Sediment Theory of Drift: *Geol. Mag.*, 1875, ii. 168.

J. G. Goodchild, Glacial Phenomena of the Eden Valley and the Western Parts of the Yorkshire Dale District: *Q. J. G. S.* xxxi. 55.

J. G. Goodchild, Glacial Erosion : *Geol. Mag.* ii. 323—356; On the Origin of Coums : *Geol. Mag.* ii. 486.

E. Sewell, Notes on the Drifts and Boulders of the Upper Part of the Valley of the Wharfe : *British Association*, 1876.

F. A. Bedwell, Notes on the Bridlington Crag and Boulder Clay : *Geol. Mag.* v. 517.

J. R. Dakyns, The Calder Valley : *Geol. Mag.* v. 46.

J. W. Davis, The Calder Valley : *Geol. Mag.* vi. 191, 313.

W. Gunn, Glaciation of the West Yorkshire Dales *Geol. Mag.* vi. 384.

On certain ice-borne boulders scattered over the summit of Norber, near Clapham.

T. N. Hutchinson, *Report Rugby School Nat. Hist. Soc.* 1878, 25.

D. Mackintosh, On the Correlation of the Drift Deposits of the North-West of England with those of the Midland and Eastern Counties : *Q. J. G. S.* xxxvi. 178.

S. V. Wood, Junr., The Newer Pleiocene Period in England : *Q. J. G. S.* xxxvi. 457.

J. R. Dakyns, On Silurian Erratics in Wharfedale : *Yorks. Geol. Soc.* vi. 159.

[Silurian fragments here were probably derived from silurian strata *in situ.*]

Prof. Phillips, Reports of Boulder Committee of British Association (drawn up by Dr. Crosskey) : *Geology of Yorkshire, Yorkshire Geological and Polytechnic Society Proceedings.*

Rev. J. S. Tuke, Notes of the Glacial Drift near Ripon: *l. c.* vi. 210.

[Gravels and clays are described, 'the valleys were filled with glaciers,' but he gives no proof of this.]

J. W. Davis, On the Source of the Erratic Boulders in the Valley of the Calder: vii. 141.

J. W. Davis, Erratic Boulders in the Valley of the Calder: *Geol. Soc. Yorks.*, 1875, ii. p. 93.

The sections at Thornhill, Dewsbury, &c., show that the drift containing the boulders is part of a set of stratified drifts, made by water and icebergs. There are no striæ or other signs of ice-action in the district drained by the River Calder. The boulders are water-worn.

Shap Fell granite and crystalline rocks occur as boulders south-east of Wakefield on the low ground (having come down the Ouse Valley past York ?). At Dewsbury these are all rounded, not glaciated, and with them is flint from the Yorkshire Wolds, as at York (arguing a current of water from the north-east). Travelled boulders do not occur above Sowerby Bridge (near Halifax). Glacial streams went east, over ground 1,600 feet high, into the valleys of the Tees, and into Arkendale and Swaledale ; also south, filling the valley between Mallerstang and Wild Brae Fell, being, according to Goodchild (*Q. J. G. S.* xxxi. 73) 1,600 feet thick. Dakyns and others think the Calder granite boulders came across from Lancashire ; but the author states that 'the watershed between Burnley and Littleborough is formed by a series of hills rising about 1,400 feet above sea-level, extending from Shievely Pit and Heald Moor south to Tester Hill, and along Trough Edge to the summit near Walden. *Throughout the whole of this district, on the Yorkshire side of the watershed, there is no trace of gravel or drift.* Drift occurs on the Lancashire side and is often 200 feet thick. Marine shells are at Hollingworth Reservoir, four to five miles west of the summit, and 568 feet high. At Calder Head is a great thickness of boulder clay. Good examples are at Cant Clough and Hurstwood Brook near

Worsthorn, &c., where carboniferous limestone boulders, granites, &c., abound. Limestone boulders are burnt for lime here. There are glacial beds at Burnley. The valley of the Calder is entirely devoid of erratic blocks for many miles from its source, and they appear only on the low ground towards its mouth. Therefore the erratics at Dewsbury and farther east did not come down the Calder Valley, but must have come down the Ouse (on icebergs), derived from the ice-stream coming down Swaledale and Wensleydale. The boulder clay of the Ouse Valley is 60 to 80 feet thick at Easingwold, 70 feet at York, and 60 feet south of the River Wharfe. 'The beds are much *contorted*, as if from lateral pressure, such as might be produced by icebergs grounding in shallow water.' (*Memoir of Geol. Survey*, Sheet 93, N.W. p. 14.)

Boulder clay occurs in the Valley of the Aire, at Bradford, Guiseley, Apperley, and north of Leeds.

A glacial stream probably descended the Aire from Skipton (?), as boulder clay 114 feet deep occurs on Whinmoor 380 feet high.[1]

Boulder clay with granite, &c., occurs two miles north of Barnsley. (Green, *Yorks. Geol. Soc.*, 1876, p. 122.)

This was brought by water from the east. If it were part of the Skipton-Bingley glacier, it would be full of limestone, not granite.

The united action of icebergs and tides is amply sufficient to account for the boulders in the Calder Valley. The far-travelled erratics are most numerous at the lowest part of the clay beds, being dropped by icebergs, while local boulders occur higher up, such as tides could bring.

Older gravels, distinct from those in the valley, occur as high as 350 feet (like the Yardley gravel). These are seen at Kirkless Park, near Mirfield, at Exley, in Elland Cemetery, at Mytholm, in the branch valley west of Halifax, and at other places as far west as Hebden Bridge. These

---

[[1] This is not till, but local detritus.]

argue a depression of some 400 feet. They are current-bedded, showing tidal action. [They were the shores of an old sea (probably pre-glacial or early glacial as in Pennsylvania). Important paper.]

J. W. Davis, On a Group of Erratic Boulders at Norber, near Clapham : *Proc. Geol. Soc. Yorks.* vii. 266.

There is an immense assemblage of erratics here, noticed by Tidwick in 1836. These are two miles E.N.E. of Clapham, near Ingleborough Mountain. A limestone plateau is strewn with masses of silurian grit, often 16 to 20 feet in diameter, which are sometimes supported on pedestals of limestone 18 to 24 inches in height—a measure of denudation; elevation 1,000 feet.

The erratics are sometimes as high as 1,200 feet, but not higher, this being the limit of the thickness of the ice.

Scratches about here have been mapped by *Tiddeman, Dakyns,* and *Goodchild.*

On Simon's Fell, east of here, striæ occur as high as 1,350 feet, going about north and south.

Striæ at Norber on grit are well preserved, going south.

The movement of the glacier is well described as *that of a great ice-sheet.*

J. R. Mortimer, Sections of Drift obtained by the New Drainage Works at Driffield: *Proc. Geol. Soc., Yorks.* vii. 373.

[The drift is clearly aqueous and iceberg-made.]

'No two parallel sections, even if but a few yards apart, would show the same appearance in the arrangement of the beds.'

Large foreign boulders and also gravel frequently occur standing on end, or nearly so.

A dovetailing of clays is universal. The mounds of clay are not moraines, but have been dropped by icebergs.

The chalk flints have been dragged along or carried by floating bergs.

[A section of boulder clay and gravel on Washington

Street, Driffield, is remarkably similar to one which I have figured on Fifteenth Street, Philadelphia.]

Icebergs grounded in shallow water on the chalk hills, and so dragged off chalk pebbles. The bergs often came from the Scandinavian ice-sheet.

'It is *only at the eastern extremity* of the chalk along the cliffs from Sewerby to Speeton, and to the extent of about one mile inland, that the boulder clays, &c., fill up the pre-glacial chalk valleys. From Flamborough to the Humber the dales in the chalk of the wolds contain no drift.

W. Gunn, Glaciation of the West Yorkshire Dales: *Geol. Mag.* vi. 384. [Good.]

He says that 'there are no foreign boulders in Wensleydale, only local ones. There are no erratics in Arkendale and none in Swaledale, except in the lowest part of the dale near Richmond, where it can be clearly shown that they came over the watershed from the north, out of Teesdale.' Ice did not pass over the low watershed from the Eden valley into Wensleydale. The ice-sheet did not cross Stainmoor by way of the low passes, but went over the higher ground farther north into Deepdale, Balderdale, and Lunedale, erratics occurring up to 1,800 feet on the watershed between the Eden and the Tees.

J. R. Dakyns, The Calder Valley: vi. 46.

Granitic boulders did *not* travel into east Yorkshire by way of Wensleydale, but over Stainmoor, for granite is absent in Wensleydale.

T. Tate, The Glacial Deposits of the Bradford Basin: *Yorks. Geol. Soc.*, 1875, p. 101.

The Bradford Basin has an outlet into the Aire Valley at Shipley. Till occurs at 400 feet in Ripley fields. It effervesces, being derived from limestone, and contains scratched limestone, fragments, &c. The till also occurs up to 626 feet, near Bierley Chapel, and is largely developed in the valley through which the Bradford Beck flows. '*It is nowhere present east, south, or west of the area drained by the Bradford Beck.*'

[Is it not, therefore, water or iceberg borne ?]

A. H. **Green**, On an Exceptional Occurrence of Boulder Clay near Barnsley: *Yorks. Geol. Soc.*, 1876, iii. p. 122.

Blue boulder clay with carboniferous limestone, fragments, &c., was found in a hollow. In one place this boulder clay seemed to dovetail into warp (laminated clay, tough, with pebbles of carboniferous sandstone, and irregular, wavy bedding). Gravel also occurred with it.

[Iceberg carried ?]

Geological Survey Memoirs

C. **Fox-Strangways**, *Geol. of Oolitic and Cretaceous Rocks South of Scarborough*, p. 31.

'Old chalk gravel' is the oldest of the superficial beds, and has the aspect of an old shore deposit. An old valley at Grand Hotel, Scarborough, has 200 feet of boulder clay, and the bottom of the valley is 100 feet below the present sea-level. The boulder clay is associated with sand and gravel.

Fox-Strangways, *Geol. of Country North and East of Harrogate*, p. 14.

Moraines. In Allerton Park and Marton are hills of gravel, considered by Sir A. Ramsay to be moraines. *Esker drift* is the name given to the gravels in the north-east part of the map. In Studley Park, &c., they have not esker-like contours. Large boulders occur on top (p. 15). Shap granite occurs in the north and east of the map within drainage of the Swale and the Ouse. 'We have never discovered granite west of this watershed.'

Dakyns and **Fox-Strangways**, *The Geology of Bridlington Bay*.

With a list of literature. The purple boulder clay is crushed and squeezed. 'At Ulrome the crush has been from the north-north-east' (p. 7).

Fox-Strangways, *Geol. of Oolitic and Liassic Rocks North and West of Malton*, p. 27.

Boulder clay rarely rises over 350 feet. Gravel occurs at Brandsby and Whereby.

FOX-STRANGWAYS, *Country around Northallerton and Thirsk*, p. 53.

Glacial deposits rise to 600 feet at the northern part of the map only. In the south not above 400 feet, except at Oulston, where they are nearly 500 feet. There is a great amount of limestone in the gravel at Osmotherley, where it is cemented (p. 54). The lower clay rises to 670 feet in places; in the gravel hinges of *Tellina balthica* are common in some localities. [Where?]

FOX-STRANGWAYS, *Geol. of County North-east of York and South of Malton*, 1884, p. 28.

'*There is a remarkable ridge of boulder clay*' from between Stillington and Whereby by Sheriff Hutton to the Derwent, and then curving round in a ridge by Sand Hutton, Gate Helmsly, and Dunnington to York. It is thickest about Whereby, Flaxton, and along the ridge to York. It is seventy feet thick at Flaxton, York, &c. There is a ridge at High Cayton, east of Derwent. 'Gravel of dry chalk valleys' occurs at Thixendale, &c. (p. 30), and is made of flint.

C. REID, *Geol. of Holderness.*

T. TATE, *Trans. Yorks. Geol. and Poly. Soc.*, 1875, p. 107.

'Quarrymen have exposed a grit surface well polished and ice-scratched, the striæ running due west and east along the northern edge of Rumble's Moor, 900 feet above the sea.

DAVIS and LEES, *West Yorkshire*, 1878.

[This volume contains much of interest, and an excellent map, showing important striæ.]

P. 196. In its passage southward the great glacier, 1,500 to 2,000 feet thick, was joined by others trending east from the Westmoreland and Cumberland Mountains, loaded with Shap granite, Ennerdale syenite, &c., which, mixed with Scotch stones, occur up the Eden Valley, and have crossed Stainmoor (1,800 feet), being found in the till of the *Swale* (?) and the Tees.

Another part of this glacier, being divided by the Nine

Standards and Mallerstang, went into the valley of Rawthey and source of the Eden. It passed into Wensleydale, rising to 2,000 feet. [?]

Striæ on Swarth Fell are at 1,950 and 2,000 feet, Bowfell 2,100 to 2,200, and till with striated stones reaches up the north side of the mountain to 2,100 feet.

The ice-stream descending Rawthey was joined by another descending Garsdale. Rysell, 1,823 feet, is striated on top to south-west, and east of here. On Widdale Fells, 2,000 feet, are similar striæ. The *upper* part of the ice went *west*, while the lower part went parallel to the direction of the valley. The mass of ice now went around the northern part of Middleton Fell, while a portion of it went south-east down Dentdale. The branch going up Dentdale swept around the northern part of Gragreth, and was turned by Whernside up Dibdale, where striæ go up to the summit. In valleys south of the Calder there is no drift. Boulder clay at Bradford, containing striated stones and similar drift, occurs at Apperley Bridge. There is boulder clay near Shipley, on Bradley Moor, at 750 feet.

In the dales south and west of Malham the boulder clay holds local stones only.

P. 210. Two glaciers descended Litton and Wharfe, and heaped up a moraine at their confluence.

Deposits of drift occur at Ripley, in which mountain limestone is almost, if not quite, absent.

About Ripon is drift with much limestone, and with some greenstone and granite, Shap.

[This would make the ice come over into Wensleydale.]

At Marton, Happeston, Flaxby, Allerton Park, &c., are *hills* made of unstratified till, gravel, and boulders, differing in contour from all other deposits. [*Moraine* ?]

P. 221. On the banks of the Nidd between Knaresborough and Cowthorpe are terraces over 100 feet high. Also a terrace at Ripley. [Is not this also the moraine ?]

P. 222. At Elland on the Calder is gravel at 400 feet [*an ancient tertiary* gravel].

Gunn, W., *Geol. Mag.*, 1879, p. 384.

The glacier did not flow across the lowest pass of Stainmoor (1,378 feet), where the railway goes, but went over higher ground farther north into Deepdale, Balderdale, and Lunedale, erratics occurring up to 1,800 feet.

Davis, J. W., *Geol. Mag.*, 1879, p. 313.

Shap granite boulders occur south-east of Wakefield, though rare. [They therefore clearly came from the Yorkshire flood.]

Flint from the Yorkshire Wold, together with granite, syenite, and trap, occurs at Dewsbury.

[This proves my remark above.]

North of Leeds granite and trap occur, with boulders of sandstone, &c.

[This shows that this drift also came from the Yorkshire flood.]

An ancient beach at 350 feet occurs at Kirkless Park, near Mirfield, at Exley, in Elland Cemetery, at Mytholm, &c.

These gravels are quite distinct from the low-level drift, and are current bedded.

J. R. Dakyns, *Geol. Mag.*, 1873, p. 62.

In the Wharfe Valley the silurian erratics go nearly to Burnsall, and not farther north than a mile and a half above Threshfield.

They do not occur on the hills west by north of Threshfield above 800 feet, and are solely in the drift of the plain.

R. Harkness, On Distribution of Wasdale crag blocks: *Q. J. G. S.*, 1870, p. 517.

Prof. Phillips, Shap Granite Dispersion described in 1836.

The boulders from Shap went NN.E. for six miles; also E. and S.E.

[See later paper by Goodchild, *Q. J. G. S.*]

R. H. Tiddeman: *Q. J. G. S.*, 1872, p. 471.

[Admirable paper, all of which is true, with a good map of the striæ.]

'On the Evidence for the Ice-Sheet in North Lancashire and Adjacent Parts of Yorkshire and Westmoreland.'

The rocks are all *moutonnée* and striated; the whole country is a vast '*roche moutonnée.*'

In the Lancashire district is a harmony of striæ along parallel curved lines. At the north they are SS.W., and farther south are more west, while about Lancaster and Morecambe Bay they curve again southward. No *local* glacier can explain this.

Those on Cowloughton Moor harmonise with these, and were made by '*ice pushing uphill* at the rate of 800 feet or more in two miles,' due to 'land-ice pushed up over the hill by pressure from behind, and obliged to maintain a definite course by ice to the right and left of it.'

Striæ on the east flank of Ingleborough run in a curved line, and *rise* as they proceed from north to south, curving from S. 10° W. to W. 40° S. in rising from 1,225 feet to 1,350 feet, and are on the edge of a long moraine-like mound, which takes the same direction as the scratches.

About Settle the striæ are north and south, and the watershed is two miles to the east.

At the highest point of Bowland Knotts, at 1,400 feet, are striæ going S. 15° E. *across* (?) the ridge. Others at 1,325 feet are SS.E. This is good proof of an ice-sheet, for no local glacier could have gone here. Between Ingleborough and Bowland Knotts are striæ going part south-east, others south-west, as if, when the glacier had diminished, it could not get over Bowland Knotts, and so divided and flowed on either side. Possibly, however, they are due to undercurrents.

The striæ seven miles west of Skipton point east, and indicate that some of the ice was discharged eastward, this being one of the lowest passes in the Pennine range across the watershed; the elevation of the watershed is 700 feet.

Striæ are deflected by Pendle Hill and coalesce again to the south of it. The striæ at Whalley in the gorge of the Calder clearly go *up* the river. (Pendle Hill 1,831 feet.)

No part of the ice-sheet south of Hawes could surmount land over 2,000 feet high.

Striæ along the coast show a great ice stream coming to the SS.E. from the Lake District and damming up the whole ice-drainage, so that it compelled it to go across the hills to the south instead of along them to the south-west. Twenty per cent. of all the striæ observed go due south.

Till is coloured by the rocks, 'over which it has been pushed.'

The direction of the till, movement of carriage, of erratics, and of striæ, are all identical.

The district east of Pendle has only local rocks.

Shells in till are not necessarily a proof of marine submergence.

Shells in the Caithness Till, according to Croll, were pushed there from the sea. Rolled stones also either were pushed up from the sea or belong in the moraine, as in the Swiss moraines.

Striæ in Anglesey go from NN.E.; on the coast of Ireland they are *along* the coast.

P. 486. The boundary of the Lake Country drift is parallel to the striæ in Lune Valley, and runs along Gate Beck Brook and thence to Lancaster.

MACKINTOSH, *A moraine* bounds and separates the Shap glacier from the great Lake District glacier. It is seen, for example, south of Kendal, about Whasset and Milnthorpe: *Geol. Mag.*, July 1871, and *Q. J. G. S.*, 1879, p. 430.

South of Milnthorpe it goes parallel to the striæ until past Central Fells, where it turns a little to the east, then over the western end of Rossendale anticlinal, and thence to Manchester.

This is parallel to all the striæ. West of this line are Shap granite and other Lake District rocks.

Prof. HULL (*Mem. on Geol. of Country around Bolton*) describes drift on Winter Hill at 1,380 feet, full of glaciated stones of granite and trappean Lake District rocks.

Mr. J. WHITAKER (*Trans. Man. Geol. Soc.* iv. 1863, p. 176) describes *flints* in the drift at Barrasford at the west foot of the Pendle Hills [eastern limit of the Channel ice-sheet], but none such occur to the east of it. [Important.[1]]

He well says (p. 487): The ice-sheet did not follow the drainage. It went SS.E., while the drainage was to S.W. 'There must have been a great barrier along what is now the sea-side plain, to dam up the mouths of these valleys to a great height and prevent their discharge of ice to the south-west. Just where this barrier should have existed we find evidence of a great stream of ice coming from the Lake District, and bearing with it rock specimens of that country. This must have been of considerable height and very persistent in its flow. This barrier was but the line of junction of the ice of the Pennine Chain with that from the Lake District, and to the eye they must have presented only the appearance of one great sea of ice: this barrier must also have been supported by other ice coming from portions of the Lake District still farther west.'

W. GUNN and T. CLOUGH, Discovery of Silurian Beds in Teesdale: *Q. J. G. S.*, 1878, p. 27.

The high Fells north of Teesdale formed an impassable barrier to the ice coming eastward. No foreign boulders occur in the Dale above Middleton.

TATE, Glacial drift near Ripon; there is a section of boulder clay near Oldfield in the valley of the Laver; and gravel at Wormald Green, Haddockstones, and How Hill. *Mounds* of drift block up and change the drainage. The valley going north from Haddockstones (Dean) is a northern and southern *boundary* between the local drift and glacial drift. The millstone grit is worn smooth at Haddockstones. There is a long mound somewhat north of Ripley.

[[1] This explains why Shap granite does not occur either in Wensleydale or in the Aire Valley glaciers. The Wensleydale glacier was then *not* necessarily a local one, but a true tongue.]

J. R. DAKYNS, On the Southward Flow of Shap Granite Boulders: *Proc. Yorks. Geol. and Poly. Soc.*, 1878, p. 60.

Shap granites went south to Kendal, where they abound, going across mountains at least 1,659 feet high, as granite occurs at that height on Sleddale Pike. Granite blocks occupy a narrow band of country whose long axis points directly for Shap. None are west of the River Kent, and none east of Grayrigg Fell.

S. V. WOOD, Junr., and J. L. ROME, On the Glacial and Post-Glacial structure of Lincolnshire and South-East Yorkshire: *Q. J. G. S.*, 1868, p. 146.

Mounds of sand and gravel, made out of the underlying purple clay, and filled with fragments of secondary, paleozoic metamorphic rocks, occur along the wold-top about Speeton, Reighton, and Hunmanby New Mill. A mass 50 feet thick is under Speeton Mill at 457 feet. Another patch at the north-western angle of the Wolds, at Thixendale Grange, is at 700 feet.[1]

Moraines; a ridge of till forms the west side of Bain Valley, from Henage Arms Inn to Horncastle.

South of there it is low, but continues to Kirkby-super-Bain.

It is a narrow ridge twenty miles long.

A narrow ridge ten miles long goes from Scrivelsby to Mavis Enderby and Wood Enderby.

There is a ridge between Bain and Steeping Valleys. It is higher than the chalk, p. 164, while other isolated patches at Fimber and Huggate are at 600 feet, being 'the earliest deposits of the post-glacial or general denudation sea.' No trace of Hessle clay is seen along the north foot of the Wolds, but it occurs high up on the east side at Swanland, three miles north-west of Hessle, and at Melton Ross (p. 175). The chalky clay, made mainly of chalk, is derived from 'the action of a continuous or capping glacier enveloping the higher elevations of the Wolds,' p. 167 [or an ice-belt possibly, such as Charnwood Forest had, I think.] The chalky clay has no marine fossils in it. It extends to the north side of the Thames Valley, and to near the borders of Staffordshire, like a great bay. As is shown by fossils and by strata, 'there appears to have been a gradual but unbroken amelioration of the climate, and no indications of anything affording ground for inference that a recurrence or alternation of severe conditions of cold took place subsequent to the elevation of the country above the glacial sea,' p. 174.

---

[1] This is 'screen,' or rainwash, according to Mr. Lamplugh. The evidence of submergence is to only 105 feet, and this is just pre-glacial. The shells are estuarine.

Proceedings of the Yorkshire Geological and Polytechnic Society contain full references to the geological literature of York, and should be used for reference.

Mr. J. E. Clark has described sections in the town. These consist of alternations of sand and clay, and show iceberg and flood action. The bottom boulder clay contains many striated stones of limestone, and is, like the Montreal till, made in water. The glacier must have ended in water, and the direction of the flood was from north to south; while the glacier came from west to east. Hence the mixture of boulders. None of those coming from the north-east are glaciated. The Rev. J. S. Tuke, of Ripley, holds that glacial streams came from the west into water which flowed from the north. There is no chalk at York, but plenty of it farther south, which confirms a south or south-south-west current over country less than 150 feet high. Boulders of lias occur at York.

A. Woodward, Glacial Deposits at York: *Geol. Mag.* iii. 384.

York

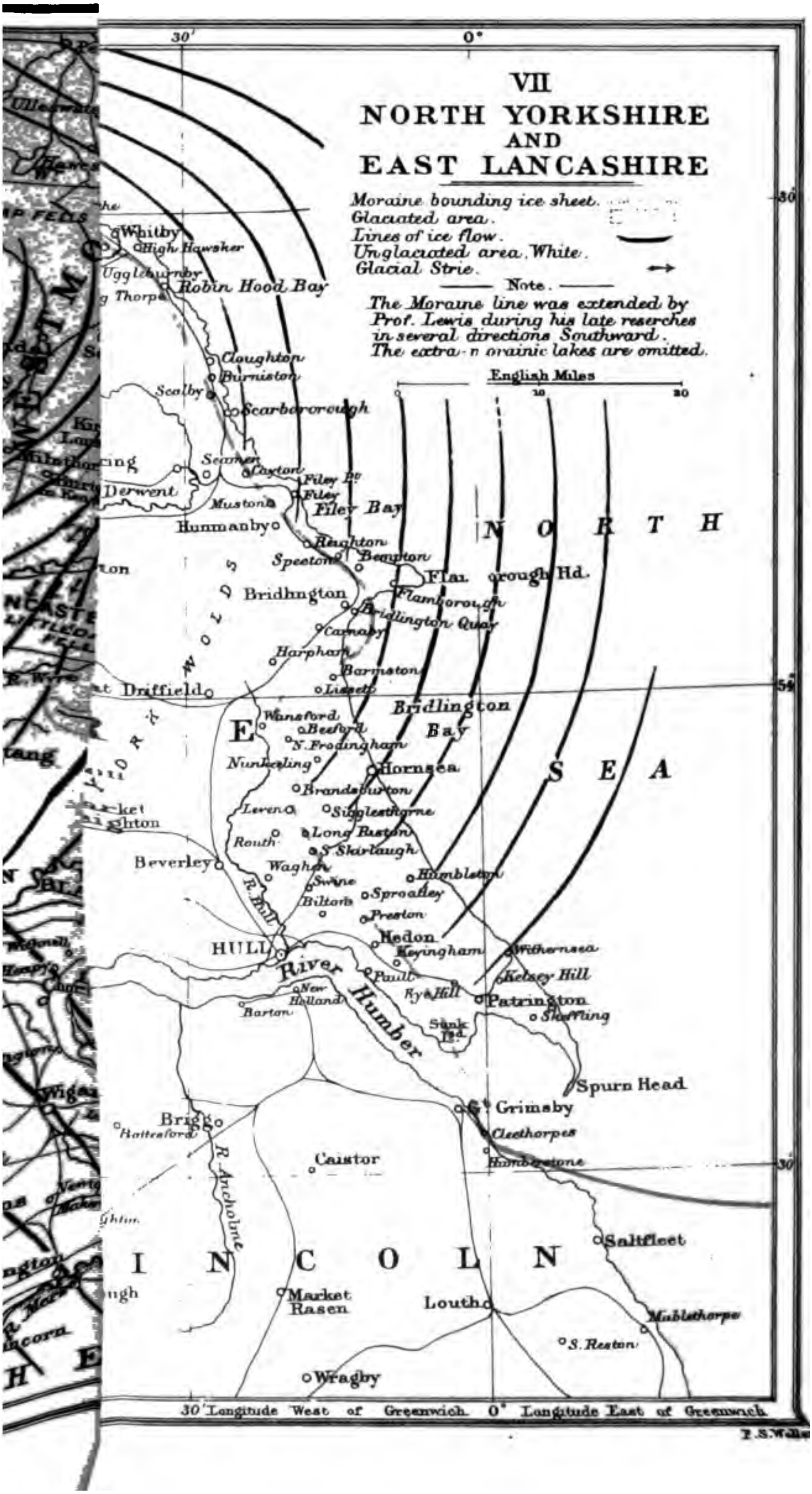
[I examined some sections of drift near the station. There is river sand on top, and below thickness of boulder-bearing clay, resembling the the Lehigh River, south of the moraine. Numerous occur in the clay, which seem to have been *derived* fro till, but have since been rounded by flood-action. Th boulders were probably borne by icebergs. One o Fell porphyritic granite (felspar twins in large cr dug up at the railway station, is 3 feet long, and is the garden of the York Philosophical Society. Bo of carboniferous limestone, sometimes fossiliferous extremely numerous. These are often scratched, pro by slipping, as boulders of harder rock are not scrat The shape of the limestone boulders shows that they made by a glacier. The boulders have been worn by w The elevation here is only 60± feet. Red gravel is very abundant here, being like the Philadelphia red g in appearance and age, as the clay is the same as Philadelphia brick clay.]

An inspection of the drift map of this region (93; New Series, sheet 63) shows that in this region drift does not rise to elevations over 175± feet. But northern quarter of the map shows much drift risin over 200 feet, which is possibly true morainic drift (?).

Unlike the drift of the lower three-quarters of the which does not appear on the Wolds (hills rising to 800 feet being driftless), the drift of this northern qu is found on the Wolds, and is seen often at 250 feet, ac ing to the map.

On sheet 93, north-east drift map, the moraine is shown as a ridge of boulder clay and gravel, about t quarters of a mile wide, crossing the map in a great almost a semicircle.

From Whereby at the north of the map, a ridge ext south-east by Sheriff Hutton, Thornton-le-Clay,



VII
NORTH YORKSHIRE AND EAST LANCASHIRE

arton, where it begins to bend southward, going to Sand utton and Upper Helmsley, whence it curves south-east by ate Helmsley, Holtby, Dunnington, Grimston, and to the uth side of the city of York. The elevations are 240 et about Sheriff Hutton, 150 feet between Flaxton and ossall, 119 feet at Holtby, and about 75 feet at York.

[This shows a diminishing height of the moraine. This the case with the local glaciers of the Gap of Dunloe, illarney, and with the Rocky Mountain glaciers.]

East of the moraine no glacial drift occurs; there is one at Bulmer or Castle Howard. In the south-east orner of the map aqueous clay rises on the side of the halk wolds to about 200 feet, but it is thin, and many atches of Keuper marl appear through it.

[From York I travel to Huttons Ambo. North of York a flat alluvial plain. There are brickyards. The plain ontinues to Flaxton. Immediately beyond the station are uttings through the drift. This is apparently a 'boulder lay' with undulating contours. There are low hills of his drift at Barton Hill Station, at 75± feet, and there a railway cutting just beyond. (All these cuttings, unrtunately, are grassed over.)

Quite steep hills rise to the north of the railway here.

At Huttons Ambo there is no drift. I walked up a hill 50 feet high, but saw no trace of it. The calcareous grit f the middle oolite came to the surface. I then went up o 270 feet, where the oolite on the hill top was decomposed nto clay, but found no drift whatever.]

York to Northallerton

[A flat, alluvial plain continues to near Thirsk. The ccasional boulders in the clay of this plain were carried, ust as those in the Philadelphia brick clay were, by ice-rafts. urrents in the water explain how there happen to be at ork boulders of oolite from the north-east, and of caroniferous limestone from the north-west.

Some low hills occur near Raskelf, but no true moraine drift. At Thirsk Junction are cuttings through coarse gravel, well shown; elevation 110 feet. Brick-yards are also here. The ground between here and Northallerton is slightly rolling in part,[1] but very level in the main.

From Northallerton I walked north to Danby Wiske. Boulders of igneous rocks, Shap Fell granite, quartz porphyry, diabase, felsite, &c., abound at Northallerton, and carboniferous limestone boulders are very abundant. Some boulders of Shap Fell granite are 3 feet long.[2]

Boulders continue on the high ground two miles north of the town, which is 250 ± feet high. At this same elevation, half a mile south of Danby Wiske, many *striated* boulders were found of conglomerate (millstone grit), carboniferous limestone, trap, felstone, felspathic ashes, sandstone, &c., and the hills are rounded in true drift contours. This is then probably the true moraine.[3]

The felspathic trap and ashes are from the Shap Fell region, west-north-west.]

Thirsk Junction

[Railway cuttings here give exposures of drift. Examination shows this drift to consist of a water-worn coarse gravel, the stones being made of trap, quartz, porphyry, limestone, sandstone, &c. Many stones are of egg-size and rounded. It is the same gravel as that at York and at Philadelphia. The high hills to the east, the 'Wolds,' are said to be driftless.]

York to Harrogate

[The alluvial plain continues to Hammerton. Between here and Cattal is a fine exposure of Bünter sandstone (pink soft sandstone, with false bedding), on which there is *no drift*. Elevation 125 ± feet. At Knaresborough there is an exposure of soft lower magnesian permian limestone at the station, and very fine cliffs of the same at the River Nidd. It looks like a soft yellow sand, with much false bedding. (A good place to study it.) Elevation 220 feet.

---

[1] Low ridges parallel to the railway occur as if made by flowing water.

[2] Several boulders of Shap Fell granite and other igneous rocks of the Lake region may be seen in the town of Northallerton.

[3] The hill close to Northallerton is artificial, having been thrown up as a defence at the time of the battle of Stanton.

At Harrogate I drove up to 375 feet, finding no drift. A quarry showed the millstone grit to be decomposed on top. A drain showed softened rock with a little clay. A house excavation on the top of a hill showed stiff clay containing rounded sandstone, and also some quartz pebbles. This was doubtful, but it was, I believe, only decomposition and not true glacial drift.]

Harrogate to Pateley Bridge

[The soil about Ripley Junction is filled with sharp, broken fragments of millstone grit, and does not at all resemble till. But gravel is seen on the sandstone in Ripley Valley, being in the valley of the Nidd River. The Rev. Mr. Tuke is clearly mistaken as to glaciation at Ripley. Openings here and there show, as just east and west of Birstwith Station, sandstone with no drift whatever on the top. The elevation here is 220 ± feet. (A series of 'fairy rings' is seen in the fields to the west, being marked by the bright green colour. They are not so large as that at Haddo House.) (The Nidd Valley is peaceful and pretty, with Tudor Gothic farmhouses. Pulpit rocks are seen near Dacre.)

The railway cuttings beyond Dacre through rock show an entire absence of drift.

At *Pateley Bridge* I climbed up a hill north of the picturesque little town to the edge of the plateau of millstone grit, 900–1,000 feet high. Large quarries were on the edge of the plateau. Neither in them nor on top of the plateau was there any trace of drift of any kind. The Nidd runs in a deep ravine. The measures are nearly flat. Magnificent ripple-marks, large and small, occur here; also many worm-burrows, closely resembling palæophycus. The escarpment is about 500 feet above the river. There are no striæ, nor erratics, nor gravel. The ice-sheet did not come so far east. The only drift in the valley is a local alluvium and gravel bordering the stream. Boulders occur in this stream drift, all of which come from the valley above. No Shap Fell granite is found in the region. (Mr. S. Mortimer and Prof. Green both say they have seen morainic drift above Pateley Bridge. There were local glaciers here.)]

York to Leeds, Skipton, Hawes, and Northallerton

[The Yorkshire plain, which continues south to Selby and the Humber, was a great waste weir for the waters of the melting glacier. On the way to Leeds the plain appears quite level to a point just north of Huddleston, where hills rise and rocks come to the surface at 110 feet, with no drift on them at all. There is a good exposure by railway cuttings of permian magnesian limestone on cliffs 50 feet high, with no drift on top; elevation 200 feet.

About Micklefield the ground is over 200 feet high; exposures of permian limestone occur which are decomposed or else simply fragmentary on top, a cutting appearing in them at 275 feet beyond Micklefield. All about here there is no trace of drift. Near Garforth, where coal is dug, the ground rises to 300 feet, with no drift of any kind. Beyond here, entering the carboniferous area, one rapidly descends into the Valley of the Aire (a smoky coal region). We tunnel through the coal measures, and find sandstone on approaching Leeds, with no drift on it. The station at Leeds is about 120 feet high; the river is probably 50 feet lower. Drift containing erratics is said to occur north of Leeds, and elsewhere in the Valley of the Aire. Some boulder drift is seen at Leeds on the carboniferous sandstone. Fine exposures of nearly horizontal carboniferous sandstone appear in cuttings of the Midland Railway west of the station. Some two miles west of Leeds exposures of the same rock are seen, and there is no drift. An elongated mound of drift occurs in the Valley of the Aire at Apperley Bridge. Just west of this, at the mouth of a tunnel, a fine fault in the coal measures is exposed on the north side of the railway. Good exposures of millstone grit are seen at Shipley.

At Bingley great hummocks of boulder-drift till, filled with boulders, occur at 300 feet. The drift fills the valley and crosses it like a great dam. It appears to be a *terminal moraine*. The town is built on it. Exposures of boulder drift are near the station. Beyond here the valley is filled deeply with drift, and a wide plain is made in which here and there drift ridges rise. The stream flows sluggishly. A great mass of boulder drift, filled with boulders, is heaped up at Skipton; elevation 370 feet. Possibly this is the true moraine, the drift at Bingley being derived from it. Future work will show which is the true moraine. Hills of drift at Skipton choke up the valley. They have true morainic contours precisely like the moraine hills in Pennsylvania and New Jersey. Low ridges of drift run into them from the back.

Beyond here for several miles large beds of till are everywhere heaped up, and many sections are made by the railway. The sections through these hills are all of the same shape. It looks as if the railway was keeping in the moraine. Soft, rounded till hummocks give a feature to the landscape, being largely developed. There is a fresh opening in them one-third of a mile south-east of Hellifield (I change here for Hawes Junction). The drift hills are now just east of Hellifield, resting on the western side of the mountain district. At North Preston rock is seen under the drift. We are therefore west of the moraine. The drift is, however, very deep all about here. The high rocky hills both east and west of Settle are clearly bared and rounded by glaciation. Fine cuttings and a large quarry of carboniferous limestone occur beyond Settle, and the till, which lies on the top of the limestone, and mantles much of the country, is filled with limestone boulders. The River Ribble is filled. Striated surfaces of slate are seen a few miles north, at Settle, at several places along the railway, and also probably in the slate quarry. A [illegible] Horton [illegible]. [illegible] north of Horton [illegible] feet thick. [illegible] is a wild region, 1,000 feet [illegible] aspect. The country is a [illegible] hills and hummocks of drift [illegible].

The limestone in this region has been [illegible], and afterwards eroded by post-glacial [illegible] action, precisely as on the Islands of Aran and as in the region south of Athenry, Ireland. Broken and [illegible] fragments of limestone strew the soil. Erosion holes and channels occur in the limestone often nearly 2 feet deep, as in the Aran Islands. It is a wild region at Ribblehead. Treeless mountains and barren country, and bleak [illegible] moors. The elevation of the railway is 1,100 feet and more. Peat beds are seen here. At the entrance to Blea Moor Tunnel, 1,200 feet, coal is exposed. On the farther side of the tunnel there is no drift. The whole aspect of the country has changed. Charming valleys, fertile farms, rocky ravines, and waterfalls now take the place of barren moors. Dent, at 1,300 ± feet, is completely different from Ribblehead, and is much more beautiful. No drift is seen at Rise Hill Tunnel, the soil being filled with sharp fragments. Hawes Junction is 1,220 ± feet high: here the sandstone is exposed, and sharp fragments of it fill the soil. Yet a few rounded boulders are seen. We now descend toward Hawes, the head of Wensleydale, and soon encounter large masses of till, piled up in fine, rounded heaps, at an elevation of some 900 feet. The drift ridges run parallel with the dale, going south-east. Immense heaps of till occur at Hawes, 800 feet. They look like terraces bordering the valley, and perhaps the valley has been deepened through the drift here. Numerous and large striated boulders can be seen from the railway, sticking out of the till. Clearly, the high mountain land about Dent stood up like an island or peninsula out of the ice-sheet, as did Pocono Knob, in Pennsylvania. The occasional perched boulders, seen at Hawes Junction, were carried by the top of the ice, which carried no till, and had no eroding power (?). Hills of till continue down the valley. They are seen at Askrigg, just below which are some good sections on the railway. Large kame-like, sandy hummocks are seen between Askrigg and Ayscarth, as are also large hills of till, filled with large limestone boulders. Below Ayscarth the valley gets more level, and many sharp fragments of rock appear. Limestone comes to the surface at Redmire, although, of course, boulders also appear. There are no more rounded hills of till. The drift is confined to the valley, and is cut out in terraces, and levelled off on the top. We seem once more to have gone through the moraine and out of the glaciated area. No heaps of till are at Wensley, and cliffs of limestone appear here with no drift whatever. But once more a heap of true till,[1] filled with scratched limestone boulders, is seen half a mile west of Leyburn, at 650 feet. At Leyburn rock appears, and immediately below there is slate with no drift upon it. The moraine is apparently just north of here. Limestone comes to the surface at the next station below. No drift was noticed at Fingall. Drift occurs below here, and many boulders, but it is sandy. At Bedale there is loamy drift, at 150 feet elevation, in great amount. The Yorkshire plain is reached at Leeming Lane, 110 ± feet, where there is a brickyard.

I can now trace the moraine from Danby Wiske to Bingley or Skipton, viâ Hawes. According to the abstracts given, the drift in Wensleydale belongs to a local glacier, and the true moraine is north of that valley.]

S. V. Wood, junr.: The absence of drift on the east slope of the Pennine Chain south of the Aire, at any altitude at all corresponding to that at which it occurs on the western slope, has long been known. *Q. J. G. S.* xxxvi., 1880, p. 514.

---

[1] Local glacier?

See the [illegible] of the Geological Survey for [illegible] Q. J. G. S. xxviii. [illegible] p. 40.

New Malton to Whitby

At Huttons Ambo middle oolite rock is exposed on the railway with no trace of drift. From New Malton a level plain at an elevation of [illegible] feet, which is along the Derwent, past Rillington and Marishes to Pickering. Here the railway enters the ravine of Pickering Beck, hills rising on either side to 400 feet, and farther on to over 500 feet, being made of middle oolite, as were the hills about Huttons Ambo, while the plain just crossed was made of the softer upper oolite 'Kimmeridge clay,' &c.). Quarries of middle oolite were seen at Pickering, and good cliffs along the valley, but no drift. Above Levisham are great piles of talus, made up of angular debris which has slipped down from the cliff sides. The valley now becomes wild, with steep rocky hills on either side, and is choked up with heaps of talus, made by landslips and avalanches. No trace of drift. The local debris is heaped up much like a glacial moraine at the highest part of the valley. We ascend to 600 feet, crossing the watershed at one mile south of Goathland. There are fine exposures of lower oolite at Goathland and all along the ravine north of it, the road now rapidly descending. Still no trace of drift. There are iron mines at Grosmont in the lias. We have now descended to 150 feet and still there is no drift. Some coarse gravel is seen at an elevation of 80 feet, two miles beyond Grosmont. No drift at Sleights was noticed, nor at Ruswarp, though only 50 feet above the sea.]

Whitby to Scarborough

[At Whitby rock is exposed, with sometimes gravel on top, but no till. At West Cliff, 160 feet above the sea, there is red gravel, clearly marine. Farther south there is clay with the gravel and occasional large boulders. We ascend to 375 feet at Hawsker. There seems to be no drift here, merely the decomposed rock. Just south of Hawsker we rise to 450 feet, where the rocks come to the surface with clearly no drift whatever. (There are fine views off to sea.) At Robin Hood Bay we get down to 260 feet at the station, and lower beyond, but no drift is seen. We again ascend high cliffs. A trap dyke, the 'Whim Sill,' produces round boulders by concentric weathering. No drift whatever.

At Peak (650 feet high) the sandstone of lower oolite outcrops. There is no trace of drift here or at Hayburn Wyke (360 feet), or at Cloughton (225 feet), unless it be in the hollows or valleys.[1]

At Scarborough in a ravine between the hills is a mass of drift, consisting of gravel, clay, sand, &c., stratified and dipping to the north.

The boulders consist of trap, sandstone, &c. (also Shap granite, &c., it is said), and are all well water-worn.[2]

Those in the beds of clay are said to be striated. This drift has been made by the sea and washed up in a ravine. It has no resemblance to till.[3]

It extends inland up the ravine, but is absent on the hills. It is clearly aqueous. The striated boulders are said to occur in the clay beds, which beds alternate with sand, &c., and are, perhaps, due to deposit from large floating ice-cakes. Mr. Fox-Strangways states that this drift occurs in a number of ravines in the neighbourhood, and rises up to some 200 feet on the hills. A very interesting phenomenon in the neighbourhood is the course of the Derwent River. On approaching the sea its old channel has been blocked up by drift;[4] and it has cut a new channel

---

[1] Some clayey drift with gravel was seen at Sealby, and probably runs up the ravine there.

[2] West of Scarborough at Seamer Junction, in the yard belonging to the station, is a large boulder of Shap granite set on end, being probably the largest found in the district.

[3] But south of Scarborough, at Osgodby Nab, there is an abundance of boulder clay; also at many other places along the coast.

[4] This is the terminal moraine.

[illegible] away [illegible]

[illegible] like that of [illegible] Blackwater, [illegible] glacial epoch. [illegible] the sea. [illegible] the [illegible] Scar- [illegible] I think [illegible] deposits are [illegible] floating or [illegible] iceberg-laden

[illegible] excellent paper [illegible] On the [illegible] Lincoln- [illegible] paper [illegible] H. Penning, [illegible] S., 1876, [illegible] currents [illegible]

[illegible] great piles of [illegible] It is [illegible] has pierced [illegible] top. [illegible] ravines opening [illegible]

[illegible] feet above the sea. two [illegible] Farther north also there [illegible] however, lies in a rock ravine, [illegible] feet. There is also

---

[illegible] —J. F. L.

much boulder-bearing drift overlying the rock south of the tunnel, south of Easington, at 300 feet.

Are we now in the glaciated area? North of here more drift is seen.

Drift, clayey, filled with stones, occurs at Lofthouse, resting upon rock.

On approaching Saltburn we get to much lower ground, where drift of course occurs.

A level plain extends from Saltburn along the sea to Stockton.

Sand dunes occur on the shore about Redcar.

Whether this region is or is not in the glaciated area is difficult to decide on account of the subsequent marine action, and also on account of the alluvium brought down by the Tees.

It *is* glaciated.]

Stockton to Thirsk

[As the railway banks are all covered with grass no sections were obtained, and it may be that the cuttings are through soft clayey rocks, not through drift. The contours of the hills are certainly not those of morainic drift, being too soft and rounded. They are either modified till or are not till at all. There are no hummocks and no eskers. It is simply a part of the Yorkshire plain.

Is the true moraine, then, north of Stockton?

(I decide to turn back at Thirsk, and go to Durham.)

The hills about Danby Wiske on second examination do not seem to be true till hummocks.[1]]

Danby Wiske to Durham

[The level country, only 150 feet high, the shape of the very low hills, the colour of the soil, the comparative absence of boulders, the tracts of clay, &c., north of Danby Wiske do not resemble a glaciated area. The cuttings show rounded, gravelly stones, not true till. This all appears to be part of the York flooded plain. It seems to be merely a covering of gravel and clay on the top of a decomposed or soft rock (trias). Sharp fragments occur in the soil.

---

[1] S. V. Wood, Junr. (*Geological Magazine*, 1872, ix. p. 175), says that the 'upper boulder clay and underlying sand extends through the Vale of York into that of the Tees, seeming to be a continuation of the Hessle clay and sand, the clay being thicker in the north than at Holderness.'

At Darlington we enter the permian, being now north of the Tees. An exposure occurs half a mile north of the station. Rock (magnesian limestone) is well exposed at Aycliffe, both in the cliffs and in a quarry. (Examine this quarry.) Till on top?

Beyond here are several exposures of rock, but not of till. At Croxdale are good exposures of carboniferous sandstone, with no till whatever upon them.]

Darlington, Guisborough, Saltburn, Lofthouse, Hartlepool

[I go from Darlington to Saltburn, viâ Middlesborough and Guisborough. Nearly flat country with low hills (of drift ?) extends from Darlington to Middlesborough.

About Ormesby we approach some high hills.

At Nunthorpe, the highest point reached by the railway, are rolling masses of what looks like sandy drift, but may be decomposed rock.

Rock outcrops on the hills on either side.

Hills to the south rise to some 700 feet, at least, near Pinchinthorpe.

These are the 'Cleveland Hills,' and are apparently non-glaciated.

(It is a lovely region about Hutton.)

The rock is soft and crumbling, and there are no boulders in the fields.

There is no sign of glaciation about Guisborough. There are numerous exposures of rock beyond here.

Some drift is observed, but it is perhaps local, for none is seen at Boosbeck, the supposed drift being decomposed rock.

A little farther east we pass through deep cuttings in which, in soft gravelly drift, are boulders of white limestone (?) or sandstone.

I examine the country about Saltburn, fine cliffs being here exposed on the sea.

I also go to Lofthouse.

Below Saltburn, as indeed down to Scarborough, the land at the sea-shore is often higher than it is inland, and rivers flow away from the sea to inland. Of course the coast-line was once much further out and has been eaten in.

About Brotton (i.e. north of Brotton), as seen by several exposures, drift is entirely absent—nor is there any on the cliff above the sea farther east; but, on my return trip, I see much drift with many boulders south of Brotton, 220 feet above the sea by barometer.

At 75 feet lower down, at Carlin How, gravel occurs; and at Lofthouse Station, and on the road just west of the station, is a deposit of true *till,* from which I collected pebbles of limestone, sandstone, red granite, &c.

The till is full of striated stones, and in fact almost all the larger boulders are striated. A glacier must have been here. Yet the till lies in a hollow on the seaward side of the hill.

I return to Saltburn and Stockton.

At Marske we enter the flat plain at the mouth of the Tees, leaving the high hills to the south. (Examine memoirs of Geological Survey to see if this hilly region is covered by till. If so it was glaciated.)

There are ridges of boulder clay on the bank of the Tees just east of Eston Grange, the first station east of South Bank or west of Redcar.

I get out at Middlesborough and cross to Port Clarence, going to Hartlepool.

(There are borings for salt at Port Clarence.)

Just north of Greatham the railway makes a long cutting through what is possibly drift, but the country generally is very flat from Port Clarence to Hartlepool.

At Hartlepool I call on C. O. Trechmann, Ph.D. He says that drift is deep all about here. Boulders of rock from the Cheviot Hills often occur. Shap granite does not occur north of Hartlepool.

On the Geological Survey Map, 103° N.E., a boulder of Shap granite is marked as occurring at Elwick (four miles west of Hartlepool).

Near here, also, is a mass of cemented drift called 'Dalton Piercy crag.'

A similar mass of cemented drift forms a rock-like mass at the 'Rock Well,' near Darlington. (See *Zigzag Ramblings*, R. J. Manson, Darlington, 1884.)

Elwick and Dalton Piercy are perhaps on the moraine of the Stainmoor Tees glacier. North of this glacial stream was one from the north-west carrying Cheviot rocks, &c.

Light breaks at last.

Bearing in mind Mr. Gunn's paper (*Geol. Mag.* vi. 384), in which Swaledale and Arkendale are said to be free from erratics except at Richmond, where the glaciation came out of Teesdale, I suggest the following:—

A glacial stream came across Stainmoor and into Teesdale, and out to sea at Tees Marsh.

The southern boundary ran approximately from the south side of Stainmoor Forest to Richmond, to Dalton, to Crathorne (?), to Ormesby, to Saltburn, to Lofthouse.

Its northern boundary merged with ice-streams from the north-west and ran to Durham. (See Goodchild's paper, *Q. J. G. S.*, for its boundary at Stainmoor.)

The region of East Yorkshire, the Cleveland and Hambleton Hills, and all southward was unglaciated, as was all the Swaledale region, and Northallerton, and the country south of the latter place.

Then a local[1] glacier started at the head of Wensleydale, and flowed south-east, its centre passing down the

---

[1] Not necessarily local any more than the Aire glacier was.

River Ure to Masham, and thence to Harrogate, while its northern boundary passed Leyburn and Ripon, and its southern boundary passed Masham Moor and Pateley Moor to Ripley.

The Nidderdale was non-glaciated, as was also the Swaledale below Burnsall.

The mountains at the head of Swaledale, north of Blea Moor, were likewise non-glaciated.

This is a much more complicated matter than I had imagined, but it is supported by *all the facts* in my possession, the striæ, the moraines, the non-glaciated regions, &c., all now fitting in.

Icebergs broke off from the Stainmoor Tees glacier and carried Shap boulders to Scarborough by way of the sea, and at the same time a great fresh-water stream flowed from Darlington to York.]

Hartlepool, Ferry Hill, Bishop Auckland, and Richmond

[I go from Hartlepool to Ferry Hill.

An enormous mass of morainic drift, full of boulders, clay, and sand, is cut through immediately west of Hartlepool.

This continues for miles, the cuttings being 50 feet deep, &c. Part of the drift is heaped up in hummocks and typically developed on a huge scale. It is probably the terminal moraine of the northern ice-sheet, as it abutted against the eastward flowing Stainmoor Tees glacier. It has clearly not been altered by water, but is as it was dumped by the ice. Deep drift is at Castle Eden Colliery, and half a mile south of Castle Eden are typical hummocks.

West of Castle Eden are more moraine hummocks. Drift continues eastward to Trimdon. East of Trimdon the rock outcrops, and we are out of the great moraine.

Rock also comes to the surface, and is well exposed (permian) all about Ferry Hill.]

Ferry Hill Junction

[I go to Bishop Auckland.

West of Ferry Hill no drift of importance occurs. It lies upon the rock as a mantle, 5 to 20 feet thick, from Ferry Hill to Bishop Auckland. Here I take the train for Darlington.

About Sheldon is bare rock with no sign of glaciation.

About Heighington the land is flat (but there was a deep cutting one mile north through drift ?), and also to the south. There is perhaps deep drift, but no morainic hills.

We reach a rolling drift-covered country, with many rounded flat hills of drift, about one mile north of the outskirts of Darlington ; not hummocks but deep drift.

I go to Dalton.

At Croft Spa the railway cuts through deep drift, which here makes moraine-like, but not hummocky, hills, through which the Tees flows.

South of the Tees the drift hills continue, and the railway makes a long deep cutting through drift.

At Dalton Junction the cuttings are not so deep, the railway having ascended to the top of the drift.

On examining the section here, I find it to be an impure clay, containing boulders of sandstone, encrinite limestone, and some unknown rocks, such as siliceous breccia, &c.

Deep cuttings through hills (of drift ?) occur half a mile east of Moulton Station, but all the rest of the country is flat and without evident signs of glaciation.

I walk about Richmond and over Richmond Moor, and see no signs of glaciation except two small rounded boulders of 'whinstone.']

Richmond, Kirkby Ravensworth, Dalton, and Downholme

[I drive from Richmond northward towards Ravensworth Castle. The country is entirely driftless until I approach the village of Whaskton, where boulders and till occur. At

Kirkby Ravensworth is the true moraine, finely shown. A very large boulder of Shap granite occurs here, and boulders of limestone, &c., abound.

The church is built on a hill of till. A ridge of drift is in the valley to the north, where is Ravensworth Castle.

There is lower land to the north. Kirkby Ravensworth stands on a ridge, the ground rises to the south, and the passage of the Stainmoor glacier along the lower ground is well seen.

The Shap granite boulder has been in great part removed by blasting. A pile of granite from this erratic now lies in a stable opposite the inn.

Moraine hills are seen to the west, and at Dalton they are finely shown. A boulder of Shap granite lies in the village of Dalton. South-west of Dalton is a typical exhibition of a great moraine-covered hill.

The fields and roads are filled with boulders, the road is remarkably bad, and the moraine which is typical is on a large scale, and not smoothed off by cultivation as it evidently is farther east. We pass sharply off the moraine on to ground covered with sharp and weather-worn fragments. The character of the stone fences tells the tale in each case, the boundary being one mile south of Dalton.

I get lost on the uninhabited moors between Dalton and Marske. No drift whatever is here or in the valley of the Swale.

I go to Downholme, and here find in a lateral valley many rounded boulders. I follow up a drift-filled valley to a fine moraine at Barden Moor crossward.

This is typically developed in drift mounds. The valley of Black Beck drained the ice into the Swale above Downholme.

The Beck has cut a gorge through the drift.

The moraine runs across the valley like a great dam and forms the watershed. The fields are full of boulders. The moraine with characteristic topography of hummocks and kettles is ascended by the road leading south-west towards Red Mire—i.e. on the road between Leyburn and Richmond.

I now turn back to Richmond. On nearing Richmond, especially at Sand Beck, are many rounded boulders of sandstone, limestone, and also of *whinstone*, the latter being quite numerous. These boulders also occur directly south of Richmond. What does this drift mean? Does it come by water from the edge of the Wensleydale glacier, like the drift which occurred about Downholme?

There are no striæ in the Swaledale or about Richmond.[1]

Bridlington

There are hills, perhaps of drift, at the edge of the oolite escarpment at Kirkham Abbey. As there is a lake at Castle Howard to the north, and two small ones near Upper Helmsley to the south, it is possible that this is the moraine. No drift appears till we reach Seamer Junction, where there is a huge boulder of Shap granite.

Just south of Gristhorpe are hummocks and ridges of boulder clay of rather morainic aspect, and after passing through these a great thickness of drift seems to occur.

The mounds are rounded as if either made in water or subsequently submerged. More low flattened mounds and ridges occur beyond Filey. At Hunmanby we make deep cuttings through the chalk, getting apparently out of the drift, and rise to higher ground (400 feet ±). I see no drift between here and Speeton Station. At Speeton village, a quarter of a mile east of the station, is a ridge of drift (*moraine*) at the windmill, at the height of 457 feet. Cuttings through the chalk beyond Speeton Station show no trace of drift, and we do not get to boulder clay till we reach Flamborough. Just beyond Bempton are more deep cuttings through chalk, in which there is no drift at all.

---

[1] For Professor Lewis' final opinion as to the meaning of these deposits see Introduction, p. xxxv. –J. F. L.

l Flamborough we see 2 feet of
: clay on the top of the chalk.

Bridlington, under the guidance of
W. Lamplugh, I examined the cliffs.
d section was found where the sea
cently cut away the wall and the
ıs exposed, and I saw the upper and
purple clay separated by a line of
ying on basement clay, which con-
seams of sandy Bridlington crag.

e basement clay was extremely tough,
t I could scarcely get a sharp pick
;. It is very full of angular and
d fragments of all kinds of rock,
ng chalk and flint, and many igneous
.nd granite, which are extracted with
ty, so very tough is this clay. It
eterogeneous mixture, a true glacial
ade by a glacier ploughing the sea-
ı. It is dark lead-gray in colour, and
.rply divided from the underlying
clay by a line of erosion.

e purple clay (lower) is of looser con-
y, more sandy, but very impure, and
l with fragments, many of which are
ngular.

ontains small pebbles of chalk (not
abundant), occasional shell frag-
angular fragments of a black, erup-
ck, some, but not many, striated
s, and is apparently also glacial.
r clay at all resembles the Wexford
and neither contains beautifully
ed stones, the whole having much
esemblance to true, stony till. There
ımerous blocks, fragments of sand-
diorite, &c., which are quite angular
ıworn.

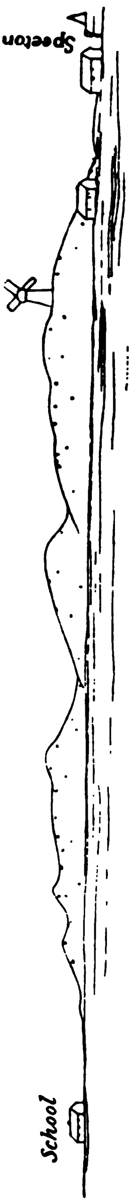


FIG. 28.—Moraine of North Sea Glacier at Speeton, on north side of Flamborough Head, Yorkshire (looking out to sea). See p. 210.

In the lower purple clay I found a fragment of coal. The pebbles and fragments in it are usually horizontal, though this is by no means universal. There are more chalk pebbles in the basement clay than in the purple clay. If they are due to two ice streams the lower one would naturally have had more chalk to work upon. The lower part of the purple clay is more stony than the upper part, as would be the case if the later ice-sheet flowed over and reworked an older till. Did this basement clay come from the north-east and the purple clay from the north? In which do Shap boulders occur? The upper layers of the basement clay are laminated and compacted as if by the passage of a second ice-sheet. A characteristic of both clays is the abundance of angular, unworn fragments.

Most of the diorites are in the basement clay, while carboniferous limestone is common in the purple clay. In the basement clay I see a perpendicular streak of chalk gravel. Coal also occurs in the sand between the upper and lower boulder clays. I found a striated pebble of coal in the purple clay near the base. I found also a fragment of jet (distinguished from coal by its brown streak) in the basement clay.

The sand between the upper and lower purple clay contains many chalk pebbles, and is horizontally stratified; it contains also many coal pebbles, and shell fragments occur. An angular piece of whinstone and many angular pieces of dark carboniferous limestone were seen near the top of the lower purple clay. The upper purple clay is similar to the lower purple clay, and is also glacial. It differs from the lower purple clay in being full of chalk pebbles.

The upper part of the lower purple clay is freer from impurities than any portion of the clay below it, and its erratics are mainly of carboniferous dark limestone, and carboniferous coarse sandstone.

In one place, where purple clay lies upon basement clay, the latter is bent over, and pressed down toward the south, as if by an ice-sheet moving southward.

The laminated clay at the junction is made so apparent y *pressure*, not by stratification. It is a part of the asement clay; and is made of the same material, while he purple clay lies unconformably above it.

(The 'Hessle Clay'—probably only a weathered purple lay—is stratigraphically on top of the purple clay, and is ometimes visible.)

These clays are true tills (?), and very unlike the Wexford arl, which is marine sediment.

The carboniferous limestone boulders in the basement lay are smaller and more rounded than in the purple lay; and Mr. Lamplugh told me they are often perforated y marine mollusca, as if they had been lying on the sea-ottom, before the ice-sheet advanced over them and took hem up. Mr. Lamplugh agreed with me as to the dif-erence in the stones of the two boulder clays, and that the lder ones came from the east, and the later ones from the orth. He said that the strangers occur in the lower clay, nd that Shap granite probably rarely occurs, and in the urple clay only.]

Speeton and Flamborough

[Drift just laps upon the chalk on the east side of lamborough Station. North of here is a buried valley, ntirely blocked and filled, almost even with the top, by assive drift. This old valley, comes out at the sea at lamborough Head, and a section of the drift filling it is ell seen. Many old valleys about here are thus filled, nd many streams have been made to flow differently by eing banked up by the moraine.

A range of drift hummocks run from Brickton to peeton, which are sandy and gravelly. (Moraine?) Similar ndy hummocks occur farther down, in the middle of olderness, and when at a low elevation (less than 50 feet ove the sea) shells and shell-fragments occur in them—owing that if it is a moraine it was made under water. he fauna is not nearly so Arctic there as in the ancient ridlington crag.

The moraine gets higher as we go northward. Between Scarborough and Whitby the drift rises to 600 feet. Here it goes to 460 feet. South of here, in Holderness, it is less than 400 feet. The glacier gets thinner as we go toward the south.[1]

In the moraine at Speeton are numerous and large boulders. Whinstone (basalt) is common; also carboniferous sandstone, carboniferous limestone, and some granite (fine-grained like quartz porphyry), &c. These moraine hills are being cut back by the sea. A block of white sandstone (carboniferous), 4 feet long, lies on the top of Speeton Mill moraine. The chalk outcrops, with no drift a quarter of a mile south of this. Typical moraine contours. I saw also a large boulder of garnetiferous schist.[2]

The moraine hides the chalk cliff completely. It has dammed up the old pre-glacial drainage, which used to go to the sea, and has turned it back, and inland, from Hunmanby to the Humber.

On the middle cliff is a bank of impure till, full of gravel and boulders, with many whinstones and striated stones—a true morainic mixed deposit—being the Hessle clay of Wood.

(Hessle clay proper of Withernsea, &c., does not occur at Hessle, according to Reid.) It contains many small angular fragments of Kimmeridge shale. Streaks of sand occur below it, then more clay—probably the basement clay.

Below this is a chalky wash, and below that a pre-glacial shell bed, in which rotten and fragile estuarine shells occur in place.[3]

---

[1] Boulders from Norway certainly occur in Holderness from Hull as far north as Cornelian Bay (north of Scarborough). See Holland, *Z. der G.* xxxi. p. 68, 1869.

[2] Get out at Lowthorpe Station to see gravel at Kelk.

[3] These shells have not been displaced. The cardiums occur closed and the shells are not at all worn, but extremely fragile. *Cardium edule* and *Tellina balthica* are very common. It is an interesting deposit older than the till, and perhaps the same as those at Craike Hill and Kelsey, which underlie the Hessle clay (see Lamplugh).

This is pre-glacial, and contains only local pebbles, and no far-drifted ones. The shells still live in the Humber. It is evidence of an old river or estuary. The valves of the shells are united. The elevation is 90 feet above the sea.

(It has been described by Phillips, and better by Lamplugh. It is under the drift and not in the purple clay.) *Scrobicularia* shows its estuarine character, and *Tellina balthica* shows that it is not older than the Norwich crag (early glacial). This subglacial drift was sheltered under a cliff in a bay, and is thus preserved, but it is very rare to find such pre-glacial beds preserved where the ice came over them.

Beneath this is lower neocomian, lying beneath a local wash. This is full of belemnites. Kimmeridge clay lies below it. The ice clearly had not great erosive action at its edge.

Fossils in neocomian readily weather to selenite by combining with pyrites. The neocomian is a black, laminated clay, and is clearly the source from which the basement is made by reformation, and to which it owes its colour and consistency.

I collected red chalk, which is below the white chalk, and was probably stained subsequently.

Lamplugh says that the local gray flints are rare in the basement clay, the flints being black or red, and of foreign origin.

There are many foreign boulders of quartz, porphyry, and granite on the coast. I find high up on the side of the cliffs a boulder of 'Rhomben-porphyr.'

A good section of the moraine hills, as they lie on the chalk cliff, is exposed at Flamborough Head by the cutting of the sea.

There is on the top a true, stony till (Hessle clay) filled with sharp and rounded fragments, then sand, and a very coarse boulder gravel below. The scratched stones are more or less worn, and are not so finely striated and preserved as in the basement clay. It is rubbishy, as in a true moraine. An ordinary moraine is naturally not so glaciated, but more rubbishy than a ground moraine. This is not a ground moraine, but is due to the melting of the ice.

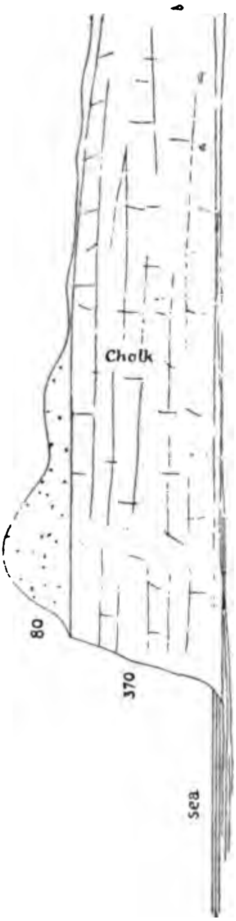


FIG. 29.—Exaggerated Section of Moraine on Flamborough Cliff.

At Flamborough Head the moraine is cut through the centre by the recession of the coast; the coast is therefore higher than the land just behind it.

These moraine mounds have been opened for tumuli, so regular is their shape. They are not kame-like in structure, but are made of angular gravel, the sandy layers being more or less horizontal, as if made by marginal waters. The boulders are not water-worn, but are shaken and shuffled, and avalanched, and roughly used by water and ice, so that the striæ are more or less worn off *suddenly*.

At another part of Flamborough Head (Buckton Cliff), on the northern side, at the south end of the drift, the drift is rudely and horizontally stratified, as if by water fringing the ice-sheet. Mr. Lamplugh has found no shells in this deposit. Even if it had fragments of shells it *need* not be marine, for soft shales, &c., lie in the till taken from the sea-bottom, and surely shells could also come. In fact, they have come in the basement clay, the Bridlington crag being transported, and even whole shells are found lying in the till.

The moraine, still hummocky, winds inland, and crosses

Flamborough Head about one mile back from its extreme point, and then runs out to seaward on the south side of the Head, to reappear again on the coast three miles south of Bridlington, near Barmston. Bridlington Bay is cut back through the moraine, and the clays on the low ground are aqueous. From Barmston southward through Holderness the moraine hills are sandy and contain marine shells, and are marked on the Survey maps. We trace the moraine through Flamborough village, still being a series of hummocks, and finally see it go off to sea, at Beacon Hill, south of Flamborough village. Beacon Hill is a sharp hummock on which lie many large boulders of whinstone, carboniferous sandstone, Aberdeen red porphyritic granite, &c., the boulders being heaped up to make a beacon. I saw a 3 feet by 2½ feet boulder of garnetiferous schist full of large garnets. This hill of drift is finely exposed on the sea-cliff, and is seen to be sandy, gravelly, and stratified within, the boulder clay being on the top. It looks like the gravels made at the edge of the ice or pushed out in front of it. A few fragmentary shells, Mr. Lamplugh says, occur in this, which is, as it were, a link joining the Speeton moraine to the more sandy moraine of the lower ground in Holderness. Alternations of coarse gravel and sand occur,

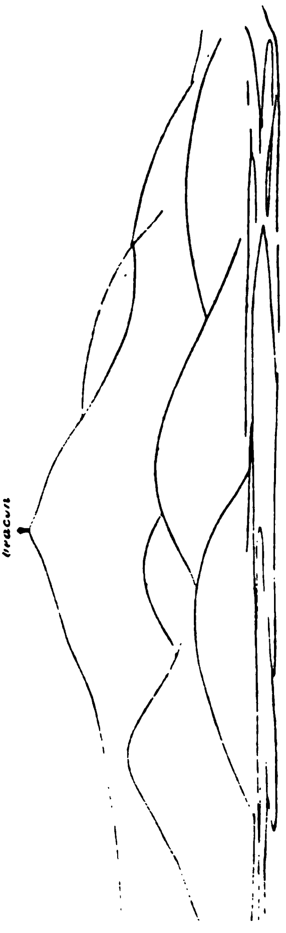


FIG. 30.—Moraine at Beacon Hill.

and it is especially sandy towards the bottom. It was apparently made in part of the glacier. (Compare this with the moraine at Llanfairfechan.) Boulder clay is also seen below.

The purple boulder clay contains broken shells, and the sand may be simply washed out of the ice; the shells being pushed out of the sea in part. At the entrance to Dane's Dyke the chalk is contorted on the surface and is overlaid by a fine series of deposits. Great masses of chalky gravel and chalk fragments overlie it, and underlie the gravelly drift and the boulder clays.

There is, I think, a fault here, and the contortion is pre-glacial. Similar contortions farther down the coast have been photographed by the Yorkshire Society, and signs of a fault occur in the ravine only 10 feet away from the contortions; I therefore believe these contortions to be pre-glacial.

Just south of Bridlington Quay is a fine exposure of the Hilderthorpe warp series, a stratified loess-like deposit, apparently due to fresh water. It is finely laminated in many layers of dust-like stuff, accumulated at the edge of the ice. Under it is a gravel, and under the gravel is the purple boulder clay. This clay looks water-made here, not glacial, being in great part stratified with chalky bands. The loess lies upon it in great sweeps.[1]

Good cross-bedding is observed in the loess, and alternations of gravel. Also fine ripple marks, as if due to an old lake. This section is very unlike that on the north side of Bridlington. The warp gets finer as we go south —i.e. as the materials are farther in the lake. No fossils occur in the warp, which is 35 feet thick. The boulder clay here is persistent, and the pebbles lie flat in large portions of it.

---

[1] See description by G. W. Lamplugh of the glacial sections near Bridlington, *Proc. York Geol. and Polytechnic Soc.*, 1882, also Phillips, *Geol. of Yorkshire*, third edition, p. 82, who called this the 'Warp Series.' In speaking of a laminated clay in the boulder clay Lamplugh says, 'it looks as if deposited in open water of no great depth, with no ice excepting light floes.'

The lowest clay (still purple clay) contains many glaciated stones, but it is a tough clay, not necessarily a till, and is quite unlike the dirty till of the Speeton moraine. *Tellina balthica*, &c., occur in it. We may be just outside of the moraine.

I drive inland to Bessingby, and see that while many boulders, often glaciated, lie on flat land, the drift thins out and chalk outcrops at Bessingby with no drift on top. It is like the thinning out of the Philadelphia brick clay against the upland terrace. The boulder drift about here extends no higher than 150 feet. Again like the Philadelphia deposit. I keep along the edge of Chalk Wold to Carnaby, then enter the flat country covered by boulder clay, going to Fraisthorpe and Barmston. South of Fraisthorpe we ascend a ridge of drift, which is sandy and gravelly. A fog unfortunately prevents better observations. From here to Barmston is a more sandy country and lighter soil.

Between Barmston and Lisset is uneven country, and some of it is hummocky. I turn up to Gransmoor, and before reaching it ascend a low ridge. There is an old mere at Gransmoor, and some boulders, and beyond here is high ground and deep drift, on irregular ground. Is it a moraine made in shallow water? There are low entrance hummocks.

The river gets stonier as we approach the true moraine (?), which is marked by high hummocks on the road to Kelk. This is *Brunton Hill*, near Little Kelk. At Fister is a ridge of till. At Brigham is another larger ridge of till, full of striated and far-carried erratics: limestone, granite, porphyry, lias, sandstone, &c. It has kettle-holes, and is a good *moraine*, well marked at the village of Brigham, which is built on it. The *ridge* extends to Foston. We go from Brigham to Driffield, and immediately enter a level ground with black soil like a moor. (This is the best soil for straw; the other for wheat.) There is level ground to Driffield.

At Driffield I visit a brickyard above the town. The bricks are made from a purplish brown clay, which is moderately pure and free from stones; it appears to be a weathered purple boulder clay, but not a till. It is apparently the aqueous equivalent of the purple till.[1]

Large boulders occur in it occasionally. It is not more than 3 feet deep, and has a foot of soil over it. It is the Hessle clay. Under it is a chalky boulder clay about 3 feet deep. This is a re-made chalk in angular fragments, it contains foreign rounded pebbles, and is clearly a wash deposit.

This again graduates into soft chalk.

It is all a fresh-water wash. The brick clay lies in the chalky wash exactly as the Philadelphia brick clay does in the Philadelphia gravels, in pots and pipes. These pots and pipes are due to the solution of the chalk wash by rains and weathering.[2]

This chalk wash is clearly the counterpart of the great chalky boulder clay of Lincolnshire.[3]

It is also the equivalent of the chalky layers beneath the glacial till at Dane's Dyke, which is there older than the purple till,[4] just as here it is older than the Hessle, or weathered purple brick clay. Driffield is clearly non-glaciated. There are no mounds of drift, and the valleys going into the chalk wolds are free from all foreign deposits.

---

[1] The passage between 'purple boulder clay' and 'Hessle clay' is seen at Bridlington at the edge of the ice-sheet, the identity of these deposits having been noticed by Mr. Lamplugh. (*Proc. Yorks. Geol. and Polytechnic Soc.*, 1883, p. 245.) In the same paper he speaks of the basement boulder clay containing much sandy wash (a passage into morainic sands which rise through the purple clay ?). Are the Sewerby gravel, the Speeton high-level gravels, the shelly gravels of the hills in middle Holderness, the chalky wash of Driffield, the basement clay of Bridlington Quay, and the chalky boulder clay all contemporaneous ?

[2] This is the cause of most contortions in the drift. Rain soaks down into the lower gravel and loosens it or dissolves it, when the upper clay or warp sinks in; and a cavity once formed the process is continued.

[3] The great chalky boulder clay occurs only in non-glaciated areas it would seem. It is of mid-glacial age; the terms mid-glacial, early glacial, and late glacial being better than inter-glacial, pre-glacial, and post-glacial when dealing with deposits made in the glacial epoch.

[4] Dakyns—Glacial beds at Bridlington, *Yorks. Geol. and Poly. Soc.*, 1879—describes the chalky gravel at Bridlington as thrust up and crushed by the ce. He calls these beds Sewerby gravels.

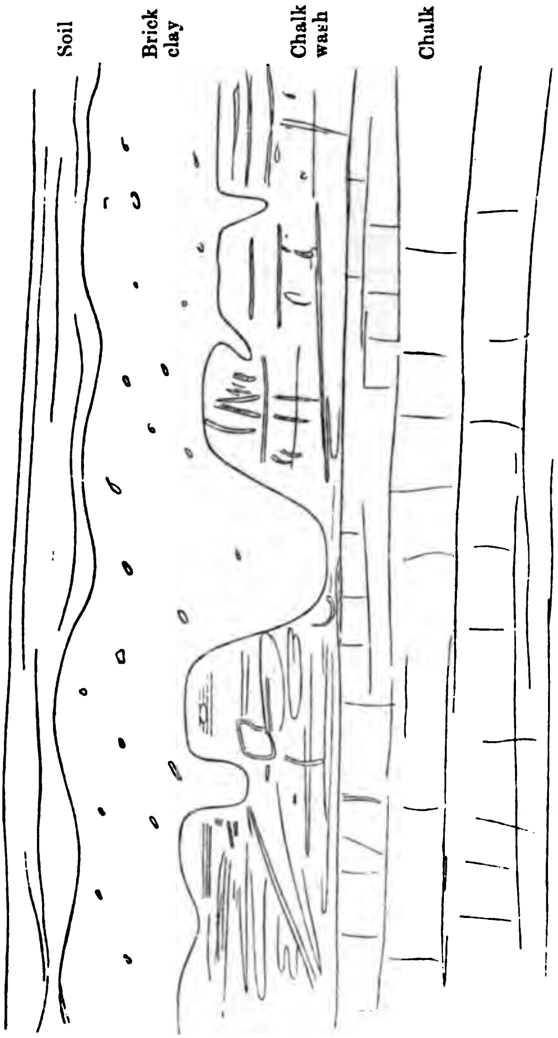


FIG. 31.—Brickfield at Driffield.

Thus it appears that one half of Holderness is glaciated, the other not glaciated, and that the line of demarcation is indicated by heaped-up terminal accumulations of drift, running the whole length of the region in a crescentic curve.

Mr. J. R. Mortimer agrees with me that the drift hills have been pushed up by the ice. He says that, with the exception of Kelsey Hill, they contain no shells, or at least only very few fragmentary shells, which are transported. At Kelsey Hill there are beds of unmoved estuarine sands filled with unbroken shells (sp. of *Cyrena fluvialis*, *Cardium edule*, &c., were kindly given me by Mr. Mortimer).

No meres occur west of the line of drift mounds, but there are many to the east of it.]

Holderness

[Just south of Garton Station, three miles west of Driffield, is an interesting sea-beach, called Craike Hill, which is terraced by an ancient stream now dry, so as to form a well-marked hill banked against a chalk escarpment. A beautifully exposed section has been cut in digging for sand and gravel. It is a true sea-sand and is covered by chalky and flinty beach gravels. The base of the exposure is a marine sand. The sand shows successive waves or tides in streaks of coarse and fine, dipping seaward, and is underlaid by coarser gravel, the whole often false-bedded. It is composed mainly of flint and chalk pebbles. Charcoal, both in sticks and in fragments, is common, especially in the upper layers.

The sand is a local tapering deposit, and is overlaid by coarse gravel of the same composition. Beside chalk and flint pebbles, many other rocks occur, such as sandstones and greenstones, rarely felsite or limestone pebbles and derived fossils. Among the last are belemnites, exogyra, ammonites, terebratula, and pecten. The most interesting boulders are those made of boulder clay, the tough clay having been rolled into boulders and coated with pebbles, just as I observed at Ballygorey, near Wexford. These clay boulders are made of tough, purple clay, and are elliptical in shape, varying from ½ inch to 2 feet in length. Recent shells, *Tellina balthica*, *Purpura lapillus*, *Cardium edule*, &c., also occur, being often broken and fragile but not much rolled. The mesozoic shells are greatly rolled. The modern shells occur in the overlying coarse gravel as well as in the fine sand, and the two deposits are clearly of the same age. Some 20 feet of this flinty sand and gravel are exposed. There is no clay in the deposit except the clay boulders already mentioned. With the exception of flint, sharp fragments are rare, and even the flints are usually rounded. It in no way resembles the gravels on Three Rock Mountain, so full of angular débris and partly worn glacial detritus. There are no stones here of characteristic glacial shape. The sand has the peculiar clean, transparent appearance so characteristic of marine beaches as distinguished from river beaches.

Lying unconformably on top of the flinty sea-beach is a horizontal layer, 4 feet deep, of warp, loess, or earthy sand. This is a soft, yellowish-brown sand, streaked irregularly with red, and free from pebbles. It is a fresh-water tidal alluvial deposit.

On the top of this sand lies a tough brown brick clay, like that which I saw at the Driffield brickworks. It contains some stones, but is a water-made clay, apparently the so-called 'Hessle clay' of Searles V. Wood, Junr. This is 2½ feet deep, and lies on a flat floor of warp, from which it is sharply defined. It is also a fresh water-clay.

The following (fig. 32) is the finest exhibition of an old sea-beach that I have ever seen.

The elevation of the top is probably about 75 feet ±, and the hill lies up an old estuary banked against the chalk cliffs. The gravels in the valley called Garton Slack, in which the Driffield and Malton Railway runs, make a perfectly flat plain, and are mapped on the Geological Survey Map as gravel of the dry chalk valleys. The marine beach

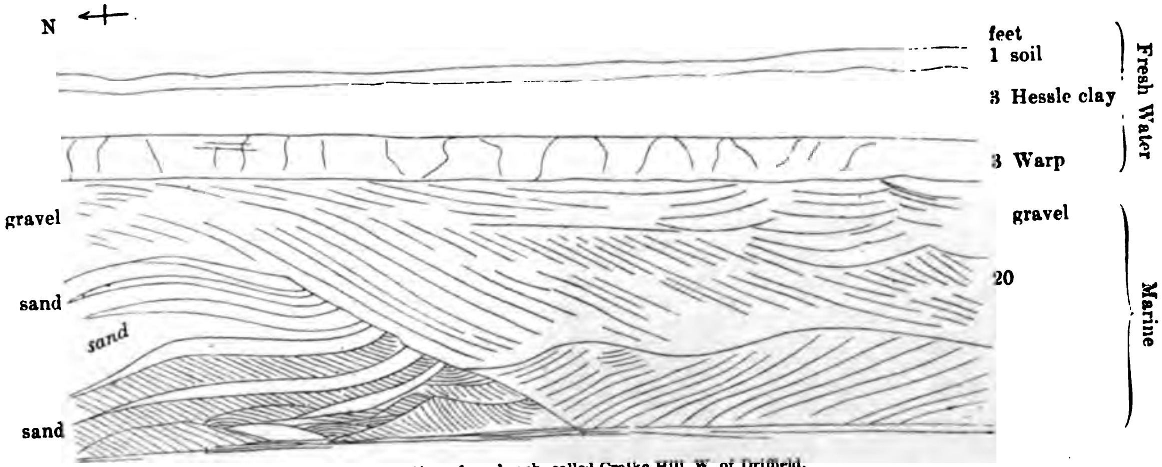


Fig. 32.—Section of sea-beach, called Craike Hill, W. of Driffield.

lies above this like a terrace, which terrace dies down as we go towards the sea. The whole beach is perhaps a mile wide, rising very gently to its apex at Craike Hill. From its contained boulders of purple clay it is clearly of an age intermediate between that of the purple clay and the Hessle clay, and thus inter-glacial, indicating a marine submergence of perhaps 100 feet.

Mr. J. R. Mortimer has briefly described this deposit.[1]]

Kelsey Hill, Hull

[I now go to Hull, and thence to Ryhill Station to see Kelsey HIll. It is a low terrace-like gravel hill, in which is a long good cutting made for gravel. We have (1) Hessle clay, chocolate with blue partings and with few stones, an aqueous clay. Under it is (2) red Philadelphia gravel, interlaminated with and underlaid by sandy layers. This gravel is full of flints and chalk and fragments of cardium, &c. Red colour.

There is more gravel below which is often coarse, and full of quite sharp shell fragments. The gravel is very flinty, and chalky, and is full of foreign boulders, exactly like the Philadelphia red gravel. The boulders are usually rounded, and coated with iron rust. The red colour of the gravel is like that of old river gravels, and as there are fresh-water shells in abundance here, the colour is perhaps due to fresh water. These gravels resemble the ordinary gravels, which cover so much of the south of England. This is less than 100 feet above the Humber, and the gravel is clearly estuarine, and outside, probably, of the glaciated district. The Hessle clay over the gravel is clearly not till, and is a deposit made in water. Kelsey Hill is not a mound, and has not the aspect of a moraine. The true moraine appears to be farther north, by Ridgmont. The gravel is full of chalk and flint, and is the same as that at Craike Hill. Belemnites and far-transported pebbles occur in it, and in the Hessle clay are drifted fragments and boulders, derived from the glacial moraine matter.

---

[1] J. R. Mortimer. 'A description of the origin and distribution of the unwaterworn Chalk Gravel on the Yorkshire chalk hills,' *Proc. Geol. Assoc.* viii. No. 5. He describes Craike Hill as marine, and says that in the village of Garton, on the north side of the valley, a similar deposit lies at an elevation of 77 feet above the bottom of the valley (this valley is about 25 feet above the sea). He is quite mistaken in his explanation of the angular chalk breccia found high up on the wolds. What he has seen is a chalk *fault breccia*, made in fault crevices, such as he has described in his excellent paper 'On the origin of the Chalk Dales of Yorkshire,' *Proc. Geol. and Poly. Soc., Yorkshire*, 1885.

I collected *Tellina balthica, Cardium edule, Purpura lapillus, Cyrena fluvialis*, &c.

This and Craike Hill are apparently of the same age as the deposit at March, Cambridgeshire.

Kelsey Hill was formed in water just in front and outside of the terminal ice-cliff of the North Sea glacier.]

Hull to York and York to Oulston

[Before reaching Husthwaite Gate we pass through hills of clayey material. At the station at Coxwold is a boulder of Shap granite. I walk southward to Oulston to ground about 400 feet high. I see no signs of glaciation except in the occurrence of boulders in the fields. But on turning west near Oulston, I reach a gravel pit made in a mound of drift. Here is a mass of re-sorted moraine material.

It is a rudely stratified mass of coarse gravel and boulders which is quite clayey, but has sandy streaks. Many of the boulders are more or less angular, although the striæ have been obliterated. They are mainly mountain limestone (with fossils and carboniferous sandstones). Other materials are rare, although I find a few chalk flints and a belemnite. Some of the sandstone may not be carboniferous. I also find a boulder of felsite (Lake District ?) This is one mile west of Oulston, and one mile east of Husthwaite. Here hummocks of drift are finely heaped up to make a beautiful *moraine* as finely shown as anywhere in Pennsylvania. Large boulders lie in the fields or are heaped on the roadside. The moraine is well shown at a cross-road, three-quarters of a mile west of Oulston.

On John Granger's farm (Thornton Hill) the moraine is finely exhibited, forming a distinct sharp ridge and characteristic mounds. I found here a boulder 2 feet long of Shap granite. This is one-third of a mile west of the village. The elevation is about 450 feet.

I go east of Oulston, and immediately enter a driftless area on passing out of the glaciated region. The moraine clearly runs through Oulston. Its line north and south of here approximately coincides with the edge of the drift as carefully mapped by the Geological Survey on maps 96 S.W., 96 S.E., and 96 N.W. The peculiar hummocky contours of the moraine are marked by the shading of the ordnance surveyors, and a series of small round hills may be seen on the map following the edge of the drift. At Boltby the drift lies against the oolite escarpment at 500 feet, and we find that it gets still higher as we go northward. The glacier at its edge was 350 feet thick at Oulston (subtracting 100 feet for the elevation of the York valley, west of here) and 400 feet thick at Boltby, eight miles to the north. It passes by Over Silton, Osmotherley, and then turns north-east by Whorlton and south of Kirkby. Its hummocky contours are well shown on the map (96 N.W.) south of Kirkby. At Kepwick, near Cowesby, it rises to 550 feet; this is three miles north of Boltby.[1]

In map 96 N.W.. north of Northallerton, and between Dalton Junction and Crathorne, the hills have a remarkable trend. The form is part of a circle with the convex side to the south. About Northallerton the hills of drift all trend NN.W. It looks as if these hills showed the ice-movement as they do in Ireland. They are all made of till. The drift rises to 600 feet on the north side of the wolds.

---

[1] A glacier seventeen miles broad and composed of two streams, one from Stainmoor, the other from Wensleydale, came down the vale of York, and was 400 feet thick at Easingwold, 500 feet at Thirsk, and 600 feet at Northallerton. It had a medial moraine at Allerton Park.

(Expl. sheet 96 N.W. and S.W., p. 53.) On the other hand, south of Oulston, the elevation sinks, and does not exceed 400 feet. Low ridges of boulder drift occur at Ampleforth Station in the valley.

At York and at Osbaldwick, close to York, large boulders of Shap granite and Lake District felsite ash occur, and are preserved in the garden of the Yorkshire Philosophical Society. A hill (of drift ?) occurs west of York.

Does the moraine run through York ?]

Allerton to Ripon

[At Hammerton we cut through soft trias not covered by drift. From Allerton I go to Hopperton and to Allerton Park to examine the *moraine*.[1]

It is heaped up in characteristic hummocks of coarse gravelly material, and contains large boulders. It is finely developed and clearly a moraine, as Sir A. Ramsay also held. There is a good exposure at Hopperton. The most abundant materials are carboniferous sandstone and carboniferous limestone. Many fossils occur in the latter. I found no granite and only one flinty pebble. The mass is here rudely stratified, and it is a waterwashed moraine stuff. The clay is in large part washed out, and the stones have for the most part lost their striations. It is much like the moraine at Oulston. It here seems to run to the north-west. There are low flattened gravel hills at Goldsburgh, but these appear to be merely gravel streams, washed south from the moraine by glacial floods. The moraine probably goes from Hopperton through Allerton Park, just north of Coneythorpe, near Farnham, and so on by Stainley to Haddockstones Farm and west of Fountains Abbey. Rock is exposed south of the moraine at Knaresborough, where there seems to be no drift visible, and where the river makes a deep gorge in the soft rock. Rock is cut through at Hammerton, and by reference to the geological map of York and vicinity a remarkable curving ridge of triassic sandstone is seen to cross the valley just north of York, making an arc of a circle convex to the south. This may be the rock ridge which I have so often noticed south of the moraine, and which may be the measure of glacial erosion. South of Madeley is a similar rock ridge. I found a boulder of coarse-grained gabbro-like diabase in the drift at Hopperton.

---

[1] The Allerton Park moraine is the *medial moraine* between the Wensleydale glacier on the west and the Stainmoor glacier on the east. Shap granite is confined to the east side of this moraine – an important proof of its character.

I go to Harrogate and Ripon. The deposit of clayey drift at Harrogate is not heaped up like a moraine, and may belong to the *Fringe*. The material and general appearance is just like the fringe. Or does it belong to another and more local drift? If I remember rightly, it contains very few limestone pebbles, whereas in the Allerton Park moraine limestone makes perhaps one-third of the mass of the gravel. Going north from Harrogate the country is comparatively level until we get to a point one mile north of Nidd Bridge Station, where are deep cuttings through what looks like morainic drift. There is a ridge and hummocks here, which now pass to the west of the railway. This seems to be the moraine, for at Wormald Green limestone outcrops and is striated.]

Old lakes were common inside of and fringing the moraine, but they have all been drained, and are only to be recognised by the lacustrine deposits of peat and clay which remain. A section of one of these deposits in which freshwater shells occur is given by the Rev. J. S. Tuke in memoir, 93 N.W., Geological Survey, p. 16. In the same memoir Mr. Fox-Strangways mentions the occurrence of other lakes (Arkendale Moor, west of Farnham, Goldsburgh Moor, &c.)

There is evidence of submergence in this district up to 100 feet. The highest river terraces occur at this height, and the 'warp clay' which covers so large an area about the Ouse and its tributaries rises to this height (l. c. p. 16). It is composed of a tough clay overlying the true warp, or tidal, alluvium. [This must be what I saw at Craike Hill. There are terraces at Ripley.]

In the same report are the following facts, p. 13: In the south-west part of map, 93 N.W., the drift is local; carboniferous limestone being almost or entirely absent the deposit is thin, and its eastern boundary is in the valleys of the and the Nidd as far as Ripley, and thence north by Crimple the narrow gorge in which Cayton Gill flows [this is outside of the moraine I have traced, and almost precisely defines the non-glaciated part of the map], p. 14. Erratic drift characterised by limestone pebbles covers all the country east of a line through Ripley and Knaresborough. The so-called middle sands and gravel have no shells in them. The moraines at Allerton Park and Marton were so considered by Sir A. Ramsay. Boulders, often 4 feet long, and unstratified Esker drift [so-called] also occur in the north-west part of the map at Studley Park [*moraine*, being *marginal kames draining the moraine inwards*], p. 15. Shap granite occurs in the north and east of the map, but never west of the drainage of the Swale and the Ouse. [That is the Stainmoor glacier kept east of this watershed, while the Wensleydale glacier was west of it. The Marton moraine may be the *medial moraine*.]

Ripon

[I find the moraine beautifully developed and sharply defined at Fountains Abbey. The beauty of the spot makes one wish to forget geology here. Nature and art have combined to make the moraine more beautiful here than anywhere else in Great Britain. Fountains Abbey itself stands close to the non-glaciated area, and the bare rocks bound the ravine in which it stands. East of the Abbey, still in its grounds, the graceful moraine hummocks suddenly rise and block up the valley, forming the curves that by the aid of art are such lovely features of the landscape. The moraine is filled with boulders of sandstone and carboniferous limestone, and forms good mounds also about

Studley Church. Running back from the moraine in Studley Park are gravel ridges of kame-like aspect, which, while truly a part of the moraine, belong to the marginal kames I have described in Pennsylvania. The River Skue flows straight down the ravine to the point where the moraine has been thrown across it as a dam; here the stream bends at right angles and forms several lakes.

I drive southward towards Markington. About one mile south of the Abbey the moraine is developed very finely. The road is lined with large boulders; great hummocks occur enclosing small meres, and it is as clearly and characteristically exhibited as anywhere in Great Britain. The highest of the mounds called How Hill[1] is covered with a castle-like building, and is one of the highest and sharpest mounds I have ever seen. The moraine is here not banked against any cliff, but lies like a great ridge in the open country. I trace it to Haddockstones Farm, one mile north-west of Markington, where an exposure shows the mass to consist of genuine unstratified till, a dirty impure mixture filled with boulders of all sizes, lying in all directions. They are often striated, but the striæ are ill preserved, as if there had been much pushing in the gravelly material. There is a large proportion of limestone pebbles. See paper by the Rev. J. S. Tuke, of Markington, on this moraine. (*Proc. Yorks. Geol. and Poly. Soc.*) I go to Markington. There are several meres enclosed in the moraine at Haddockstones, but they are now for the most part drained artificially.

How Hill is 575 feet high.

The moraine runs past Winksley and follows the line of the permian beds. Kirkby Malzeard is 523 feet, &c. It goes one quarter of a mile west of Fountains Hall, and then south of Haddockstones to Newton and Knaresborough. I go west across Cayton Gill to the non-glaciated area. The Cayton Gill rock is apparently made of volcanic ashes.

---

[1] Marked on the Ordnance Map as 'The Tower,' 575 feet. This is not entirely a hummock of drift, being made of rock capped by drift, I believe.

After crossing the valley of Cayton Gill I see no trace of glaciation. A few rounded stones continue a little way uphill, and then they disappear and the region is free from drift of any kind. The moraine sharply marks the line here. The moraine passes the village of Markington, and is heaped up in characteristic mounds and ridges.

One of these drift mounds is so symmetrical in shape that archæologists have supposed it to be a 'barrow,' and in the vain hope of extracting antiquities from it have recently penetrated it by a tunnel. I have seen several other moraine hummocks in other parts of the kingdom which have been similarly misinterpreted by archæologists. The same mistake has been made in America, where hummocks of drift, both in the moraine and in kames, have been supposed to be 'Indian mounds.' The mistake is most natural, since artificial mounds are frequently larger than the glacial hummocks we are considering. I noticed several circular sink-holes in the moraine about Markington, which are kettle-holes of glacial origin. The origin of kettle-holes is uncertain. Whittlesley suggested that ice froze in the moraine and then melted. This is quite possible, since ice lies under drift in the Sierra Nevada and in the moraine of the Alaska glacier (as told me by Mr. Lamplugh).

The moraine here has dammed up a valley and reversed the drainage, as is its habit. (See examples in Holderness, about Scarborough, in Cherry Valley, in western New York, &c., &c.; also in the valley of the Blackwater, &c. Make maps of all these.) The valley of Cayton Gill runs from north to south. A stream comes down the valley in a natural manner until it meets the moraine thrown across the valley like a dam. The stream is thus caused to turn at right angles, desert the old valley, and cut its way by a backward and winding route through the moraine to the River Ure, instead of flowing straight on to its ancient outlet into the Nidd at Ripley.

The Rev. J. S. Tuke (Markington, near Ripley) gave me a pebble of supposed Shap granite which was much rounded.

Shap granite is extremely scarce in this region, and is believed to be entirely absent in Wensleydale. He had found fragments of silurian rocks also, showing that the Stainmoor glacier came here, but the greater abundance of Shap and Lake District rocks east of York and on the east side of the valley shows that the main stream was on the east side of the vale of York.[1]

The moraine is well-developed south of Fountains Hall, and is about one mile and a half in width.]

Striæ in Wensleydale.

On sheet 97 S.E. striæ are given:—

1. Half a mile north of Swinethwaite, on the south bank of the River Ure, east and west on carboniferous limestone.
2. One mile east of Harmley, on the railway, on limestone, E.N.E.
3. One mile south-west of Fingall, on millstone grit: two localities, E.N.E. and E.S.E., the former on the road near Hutton Hang, and the latter near Hutton Hill. Elevation 550 feet ±.
4. Mr. Davis found striæ on Penhill Beacon, the top of which is 1,685 feet. See also his *Geology of Yorkshire* for other striæ.

Masham

[One mile before reaching Masham we see morainic hills, and cut through them. They form characteristic mounds and ridges. (The Rev. Mr. Gorham tells me that moraine mounds occur at Jervaulx Abbey and Park.) I go west toward Fearby, and about one mile from Masham meet a ridge of drift. An opening shows this to be true, unstratified, stony till, in which the boulders are limestone and sandstone (carboniferous). Characteristic moraine mounds made of clayey till appear about Fearby Cross. At Fearby we ascend the hill to higher ground, and at 500 feet run completely out of the drift. The line of the moraine sharply divides the glaciated from the non-glaciated area. I do not find a single boulder of limestone west of Fearby, and weathered fragments of sandstone strew the ground and make the soil.

---

[1] This occurrence of one kind of rock on one side of valley and another on the other side is characteristic of a glacier as distinguished from a river.

The moraine runs south-east by Shaws and Swinton to Nuthill. We go about one mile from Fearby, then turn northward on to gravel, 780 feet high, and through Ellingstring. On this high ground there is no trace of foreign drift, sandstone, in weathered blocks covering the fields. Two exposures show no drift on fresh-broken sandstone. The local detritus is often deep over these wild moorlands.

We then descend the escarpment called Witton Fell, going north toward Jervaulx Abbey, and look down upon a soft line of drift hills. The moraine at 500 feet forms a sharp line, abutting against the escarpment of Witton Fell. The limestone boulders appear contemporaneous with these mounds. The edge of the moraine passes the farm called High Newstead, one mile south of the Abbey.

Between here and Jervaulx Abbey the moraine is seen to lie in two or three parallel ridges, parallel to the valley and to the direction of the ice, being, in fact, a series of lateral moraines. On the road back from Jervaulx Abbey to Masham we keep along the moraine, which is well shown and displays some curious features. Some remarkable terracing occurs, possibly artificial, but perhaps made by the glacier, when smaller, pushing along its lateral moraine. About High Ellington, for example, is a mound ridge like the hill terraces for grape vines on the banks of the Rhine. It is parallel to the valley.

These terraces are small and sharp, perhaps 4 feet high. Are they due to different levels of the river? Still more curious are the parallel embankments and trenches which run at right angles to these on certain hills. They are at regular intervals running from top to bottom of the field; these are more probably artificial. The moraine is here in such mass, and is so distinctly shown, that it is to be hoped that careful studies of its features will be made by a local geologist.

Thus the moraine of the Wensleydale glacier runs into that of the York glacier, crossing the river Barn, near Shaws, passing near Nutwith Common, toward Kirkby Malzeard, to the River Laver and Winksley (all this being approximate), and then following closely the western edge of the permian limestone to Fountains Abbey, Haddockstones and Markington, &c.]

Leeds

[The only drift to be seen here is in small rare patches, lying in hollows. It is a stiff clay, with erratics of the same kind as are found in the vale of York.

I believe that these drifts were made by a temporary lake caused by the *damming up of the mouth of the Humber by the Scandinavian ice-sheet.* This sheet was 450 feet thick, and would temporarily dam up the Humber and form a great inland lake, which would pour over the country to the south in *débâcles,* making gravels, and would leave traces of its shore lines upon the east side of the Yorkshire hills and up the valleys of the Aire, Calder, &c. No fossils occur in these drifts, and they could not be expected under such circumstances. 'Modern glacier lakes commonly show a similar barren character.' *Geol. of Cromer,* by Reid, p. 88.

I now see that by damming up the Humber east of Hull we can explain all the gravels of central England. A torrent, or *débâcle,* would burst over central England, going by way of Derby and Rugby into the Avon. The area between Nottingham and Leicester would lie in the middle of this torrent, Charnwood Forest being an island in the stream. Thus we need have no marine submergence of more than 150 feet for any part of England. Streams coming from the end of the glacier at Shrewsbury, &c., would go down the Severn at the same time.]

Leeds to Louth

[I go from Leeds to Louth viâ Doncaster and Lincoln. From Leeds to Wakefield is a high driftless area. At Wakefield we reach a flat plain, the valley of the Calder, probably levelled with aqueous drifts. We then pass through many rock cuttings, showing an absence of drift. No trace of drift is seen about Nostell, for example. At South Kirkby we reach somewhat lower land and run along a level valley, in which there may be a few feet of loamy clay, but rock occurs beyond here. A broad flat plain is reached before arriving at Doncaster. A slight elevation here shows that the drift is not deep, soft, red, triassic sandstone coming to the surface. A flat plain follows, gravelly clays covering it. It looks like an old lake basin, being a dead flat, known as Misson Level. At Walkeringham, close to the Trent, are 20 feet cuttings through the drift (? grassed over) which here seems to be deep. At Gainsborough we cross the Trent, and climb up a bank made of soft red Keuper shales, containing layers of white concretionary limestone, but with no drift visible. Then comes the dark flaggy lias, the liassic yellow sands follow higher up, and we pass along a flat stretch of country to Lincoln.

The cathedral stands upon a high escarpment here, but we keep along the flat to Bardney, again apparently passing over a lake basin. At Bardney an exposure in a brickyard shows a black marl or fireclay, a thin coating of chalky gravel being on the top. We now go north-east. Low, flat undulations on the plain show on the railway cuttings that there is some chalky gravel here, sometimes 10 feet thick. At East Barkwith is gravelly clay and a nearly flat country. The stones in the clay are largely flints, I think, and are perhaps larger than they were at Bardney.

At South Willingham we enter hills of a tough black marl, the Weald clay (or Kimmeridge). We then enter chalk hills by a tunnel, and cut through a series of moraine-like mounds of chalk or white chalky stuff, half a mile west of Donnington-on-Bain, the cutting being 40 feet deep. It forms a moraine-like ridge. To the east of Donnington is an escarpment of chalky stuff and red sand. (Is not this a decomposed rock ?)

We cut through this escarpment by tunnel, and I see that the red sand underlies solid chalk, and is the red chalk. The chalk is much decomposed and broken into fragments, and has apparently no drift on top, as is seen in a good exposure at Withgall. (Are these mounds its characteristic denudation form ?[1])

There is no drift at Hallington, near which is a quarry in the chalk. Half a mile west of Louth are cuttings in the clay containing flints.

Chalk with no drift is exposed in the town. About the streets are many large foreign boulders. The largest is one of basalt, measuring 3 x 4 feet in the yard of Burdett, the bookseller.[2] Another in the street is of actinolite schist, also from Norway perhaps. Others are of limestone, called the 'Blue Stone,' and the Blue Stone Inn is named after it. The inner and outer banks off the coast may be the moraine. The moraine may run off at Cleethorpes, for there are here banks of till, which continue one mile south of Cleethorpes.

I collect about Louth many Scandinavian boulders.[3] In a brickyard I see Hessle clay—a tough brown clay with many chalk pebbles, and with occasional far-carried erratics, sometimes glaciated; also a glaciated piece of chalk. It is an aqueous clay, filling the valleys like lakes, and making them level bottoms. No moraine mounds nor trace of morainic character are observed in this clay.

---

[1] I am told that these hills of chalk débris are all drift, and not unmoved chalk. Chalk does not weather in this way. It is apparently a chalk disturbed by water and ice, and is the representative of the 'chalky boulder clay.' Here then the chalky boulder clay has its origin, being here made altogether of chalk, clay being absent. Is it not due to torrents of water rushing westward and bearing cakes of ice?

[2] This Blue Stone has been known for 400 years, and is one of the local antiquities, certainly of considerable interest. (See *Notitiæ Ludæ*: Louth, 1834, p. 243.)

[3] Among these is the typical augite syenite, which occurs only at Langesund fiord, near Breng, and also porphyry and granite from the same region. All these rocks came out of the Skager Rack, and were brought by a glacier going south from Christiania and then south-west. Other rocks came from near Frederiksvorn on the same coast.

At Welton are large pits in flint gravel. This is a remarkable gravel. I found a basalt boulder and a sandstone boulder in it. The gravel is made almost entirely of flint,[1] 30 feet deep, with layers of clay and sand as if marine. The flints are sharp and angular, and partly stratified. There was water on top of it. This is where a river from the wolds emptied into the great lake. It lies in a tributary valley at the entrance to Welton Valley. A good point to get the elevation, marking the height of the lake, or the point of *overflow*.[2]

It is an interesting fact that there is a very much larger proportion of Scandinavian boulders here than there was in the moraine at Holderness. There the boulders were mainly of whinstone, limestone and sandstone, from the north; here they are mainly Scandinavian Laurentian rocks (syenite, gabbro, norite, schist, &c., &c.). So it was in the fringe in Pennsylvania, in which far-travelled rocks from Canada were the most numerous. Here, too, is a fringe. An explanation in both cases is that the far-travelled erratics rode on the *top* or in the upper layers of the ice, and that the local materials were below. The latter were left in the terminal moraine dropped in the sea outside of Lincolnshire, while the former were carried on icebergs which stranded here with their freight. The icebergs, which must have been large to carry such a boulder as the 'Blue Stone,' grounded against the first high ground at the chalk cliff at Louth. Smaller icebergs freighted with small boulders got into the estuaries as far in, for example, as Welton. All the largest boulders were stranded on the main shore at Louth.

---

[1] This is the boulder gravel made entirely of flint, which occurs about Cromer. 'They commence just where the chalky boulder clay ends' (Reid's *Geol. of Cromer*, p. 117, and *Memoir of Country around Norwich*, p. 129, and Wood and Harmer, *Supplement to Cray Mollusca*, *Pal. Soc.* Introd. p. xxvii). It is also called 'cannon-shot gravel,' being a local modification of chalky boulder clay, due to the action of a powerful current, or, as Reid suggests, made in an ice-dammed lake liable to sudden floods. The stones frequently have their longer axes vertical, and the flints are often quite unworn.

[2] Is not this gravel due to the bursting of a marginal lake? It would thus connect the Hessle clay of the lake with the chalky boulder clay made when the lake overflowed to the west side of the wolds, and would be the connecting torrential stream.

So, too, the bursting of the second lake, that of the chalky boulder clay, to the westward, formed the flinty gravels of the Midlands. Thus we have a series of *débâcles*.

The Hessle clay runs into all the chalk valleys. None of those valleys are choked up by mounds of drift as they are north of Flamborough Head. The clay comes up to an equal height in all these valleys, reaching nearly 400 feet. There was a submergence of 150 feet when these clays were formed, but the edge of the glacier must have been at least 500 feet thick. I suspect it to have just touched North Lincolnshire about Cleethorpes.

'The short section at Cleethorpes half a mile in length is the only cliff between the Humber and Hunstanton in Norfolk.' The boulder clay here is purple and stony, and 100 feet thick. Reid's *Geology of Holderness*, p. 35.

Reid makes no distinction between true till and boulder clay.]

Louth to Cleethorpes

[Above Louth is a very low, flat ridge of local character, parallel to the chalk cliff, but a quarter of a mile east of it, made of Hessle clay. It has none of the characters of a moraine, but has the shape of a subaqueous sand bar or mud bank. It dies down here and there. I believe it to be a true mud bank formed near the shore of the Hessle lake. It is not over 20 feet high at the highest parts.

It lies between the railway and the Wolds, while east of the railway is a dead flat, sloping slightly towards the sea. From about North Thoresby and to the north of that locality, the land seems to slope upward in a level sheet to the wold cliff. This region is in striking contrast with Holderness.

At Cleethorpes I found a cliff 40 feet high, made of tough, unstratified, stony till, full of small sharp fragments of various rocks, and pebbles of Scandinavian Laurentian rock, also striated boulders and boulders of Laurentian from Norway.

I collected a boulder of red porphyritic granite from the till, and found a boulder of porphyry on the road. Borings show the till to run down 40 feet, so that it is 100 feet thick here (see *Geology of Holderness*, p. 36). This is the extreme front of the moraine, the greater part of which is out at sea. It is a limited exposure only half a mile long. It is identical with the till of Bridlington, and is enough to prove that the Scandinavian glacier formed a *dam across the mouth of the Humber* 500 *feet high*. The consequences of this dam are important and far-reaching, and explain the glacial deposits of a large part of middle England.]

Here Reid found a boulder of Rhomben-porphyr, &c.[1]

For the moraine at sea, consult maps of the Coast Survey. South of Cleethorpes, with the exception of *sand dunes*, the coast of Lincolnshire is perfectly flat.

Skipton, Oxenhope, Ingrow, and Halifax

[The railway cutting just east of Skipton goes through a morainic hill of drift, full of limestone erratics. The valley of the Aire east of here is deeply filled with drift, which is level on top.

Drift hills lap up on the sides of the valley.

At Oxenhope there is no drift whatever. I walk on the road leading south towards Hebden Bridge, up to Oxenhope Moor, and find the region driftless. There is not a single erratic or rounded pebble, and the soil is filled with frost-broken fragments of local sandstone.

---

[1] *Geology of Holderness*, p. 41.

It is exactly as in Pennsylvania. The ice-sheet has come southward up the Worth Valley, but has suddenly ended north of Oxenhope. There is a most marked resemblance here to the Pocono Mountain region of Pennsylvania. Not only is it similar from a glacial standpoint, but by lithology and topography it is the same.

The sandstone here is identical in appearance and in structure with the Pocono sandstone. It has the same plant remains, weathers in the same way, and the 'moors' on top of the mountain, barren and sandy, are the same as the 'Shades of Death,' &c., on Pocono Mountain.

From Oxenhope Moor I turn northward and walk across Haworth Moor, which is also driftless.

On the north side of the moor I find some rounded sandstone fragments, then some pebbles of limestone, and finally one of granite, 6 inches long.

I am in the *fringe*.[1] The moraine cannot be distant, yet I find no drift in the valley, nor at the south, nor for a mile westward, or a mile eastward, and there is none at Haworth except at the Midland Railway station. Here is a thin covering of drift on broken rock, limestone pebbles and scratched sandstone also occurring; apparently a 'fringe.' Below Haworth on the railway I see rock with a little drift on top down to Oakworth (one mile below), where rock is exposed.

Immediately below here huge hills of drift occur stretching down to Damems, where it is seen at the station. This is clearly the *moraine*. At the next station, Ingrow, I get out and go to the station on the Great Northern Railway. Here is a fresh section through typical till. It is precisely as in the mountainous part of Pennsylvania. It is entirely *unstratified*, and is full of far-carried and finely scratched boulders, as well as an abundance of local stuff, angular and worn sandstones.

---

[1] This fringe is due to the damming up of a stream by the ice to the north.

The limestone pebbles being far carried are smooth, but finely scratched.

I go from here to Halifax, viâ Thornton. It is a new railway with fresh sections.

Above Ingrow are good and deep exposures of stony till, full of glaciated boulders.

A mile farther on we go through a long tunnel, leaving the valley of the Worth, and emerge in a driftless area, not a boulder or pebble occurring.

The *moraine* is then just south of Ingrow on the Great Northern Railway, its fringe extending to the tunnel.

Cullingworth is driftless, so also is Wilsden. An exposure is perfectly fresh here, and shows the sandstone overlaid by a clay containing rounded boulders of the same sandstone,—a sort of local drift.

It is this same local drift overlying non-glaciated rock, and unaccompanied by any glacial phenomena, except the occasional scratching of the local sandstone fragments and boulders, that has several times puzzled me in Pennsylvania and in Ireland.

We then enter a region entirely free from drift of any kind, as the fresh cuttings about Denholme and Thornton show.

Beyond Thornton the cuttings are not so fresh, yet fresh enough to prove that there is no trace of drift; and there is none about Holmfield, Ovenden, or Halifax.

It is told me that in the bottom of the Calder River below Halifax, elevation 200 feet, there are boulders of granite, trap, &c. These have been brought by water, and perhaps floating ice.

Are they from the east?

It seems so, since limestone boulders are absent, but trap, granite, and syenite are common.]

Bradford, Bingley, and Ilkley

[Between Halifax and Bradford I go by way of Low Moor.

The country is entirely driftless, until we reach a point half a mile south of Low Moor Station at the north end of the tunnel. Here there are deposits of drift made of sandstone, in rounded and sharp fragments, in loose detritus, forming a mass at the end of the tunnel.

I get out and examine it, finding it to be merely ordinary atmospheric débris, purely local, due to ordinary denudation, slips, and local washing.

North of the station are more exposures showing an absence of glacial drift, which is also the case at Bradford.

From Bradford I go (Great Northern Railway) to Laister Dyke, between which and Bradford are excellent fresh exposures of rock covered by detritus, glacial drift being entirely absent. An exposure at Laister Dyke Station is fresh, and shows no signs whatever of glaciation.

I go to Shipley, the railway making good fresh cuttings through sandstone, and a local clay full of sandstone fragments.

No till is seen at Eccleshill, but decomposed sandstone with clay. So at Idle, where some of the sandstone fragments are rounded by atmospheric denuding agencies.

At Thackley some large scratched boulders of sandstone lie in the clay, which rests on non-glaciated sandstone.

They are scratched longitudinally as if by ice, and seem to be in the *fringe*; or, being at the edge of the Aire Valley, they are perhaps iceberg-carried.

Sections beyond here show non-glaciated rock. Drift occurs in the Aire Valley. At Shipley Station of the Midland Railway rock with no drift on top is freshly exposed. I take the train for Bingley.

Just above Saltaire coarse drift full of boulders occurs. It forms a series of hummocks and is unstratified.

Below Bingley, which is built upon the moraine, a ridge of drift crosses the valley like a great dam. North of Bingley are mounds of stratified drift, a frequent occurrence at the back of the terminal moraine.

I return to Shipley, and take the train for Ilkley.

From Shipley to Baildon we cut through rock. Only occasional rounded pebbles are seen. A thin covering of drift appears beyond Baildon Station, but rock comes to the surface farther on. There is no drift at Esholt, and fine deep fresh cuttings just beyond show that no trace of drift occurs between this place and a point half a mile south of Guiseley.

High grassy slopes bound the railway here, and the grass covers everything as far as Menston and Burley, but, as pebbles occur at the latter place, I suspect that all this is drift. The country looks even and drift-filled, and is lower than that we were in near Esholt.

The moraine possibly crosses the railway near Guiseley (near the north end of the tunnel ?).

Above Burley we see the River Wharfe, meandering in a drift-filled valley.

I drive from lovely Ilkley northward on to the high moors, and find no drift *anywhere*. The rounded fragments of sandstone are due to weathering. All rock exposures are uncovered by drift, and no limestone or other erratics are seen in the fields or fences.

I therefore go west-north-west on Beamsley Moor, and then viâ Beamsley to Bolton Bridge, seeing no drift whatever until reaching the plain of stratified drift in the valley of the Wharfe.

At Bolton Abbey (one of the loveliest spots on earth) there is no drift visible.

The pebbles in the river are all local, and I find no granite among them.

Fine sections are exposed on the new railway now being constructed between Ilkley and Skipton. On this railway is a fine synclinal in limestone in a quarry near Bolton.

Immediately west of this quarry is a magnificent exposure of typical, tough, unstratified till,[1] full of limestone boulders, all of which are striated. The till is black and extremely hard and compact, so that the stones must be hammered out of it. The pebbles are beautifully and typically glaciated, and the till is the most typical I ever saw—no trace of stratification—a true moraine (?), the boulders are often 3 feet long. I drive along a limestone valley to within two and a half miles of Skipton. I see no typical moraine hills, and not many boulders in the fields, nor do I notice striated or smoothed rock surfaces. The glaciation is slight and the glacier must have been thin. I turn south to Draughton and here see a double anticlinal which was photographed by the Yorkshire Geological Society.

---

[1] This dense boulder clay was made under water, when a marginal lake dammed up by the great glacier at Skipton filled this valley. No striæ on the rocks occur here. The excellently preserved striæ are in accordance

There is almost no drift here. On the high land between here and Addington no drift is seen. Sandstone comes to the surface about the reservoir, and the region is driftless. No limestone boulders occur here.

After all, perhaps the 'very typical till' just described is not glacier-made, but was deposited in a *lake, dammed up at Skipton by the glacier, icebergs floating in it as in the 'Marjelen See.'* The till is too dense to have been dropped from a glacier. It is like the dense clay at Montreal which contains scratched boulders and marine organisms together, being clearly of aqueous origin.] Similar till is reported as occurring in the hollow in which Bradford stands (Davis and Lees, *West Yorkshire*, p. 208), and it is described as a bluish, very tough clay, containing numerous rounded and sub-angular stones covered with striæ, the stones all coming from the Aire Valley, being limestones and grits. Patches of similar drift also occur in the Aire Valley. Such boulder-clay lies in hollows, does not form hummocks, and has not been 'dumped' by a glacier.

The boulder clay here described is caught on the northern side of a limestone hill.

---

with what I afterward observed in Co. Wexford, Ireland. This deposit is such as is made in Swiss dammed-up lakes and in the Arctic Sea near the foot of a glacier (Brown, *Quart. Journ. Geol. Soc.*, 1870, 682). It is my *fringe.*

[The moraine of the Wharfe and Litton glaciers is probably at the confluence of those two streams.

The Wharfe perhaps once joined the Aire near Skipton, and when turned out of its channel by drift, cut a new path by way of the 'Stridd.']

For the glaciation of Upper Wharfedale see 'Notes on the Drifts and Boulders of the Upper Part of the Valley of the Wharfe,' E. Sewell, *Brit. Assoc.*, 1876, p. 94; 'On Silurian Erratics in Wharfedale,' J. R. Dakyns, *Proc. Yorks. Geol. Soc.* vi. 210; Green, *Geol. of Yorkshire Coalfield*, 1878; *West Yorkshire*, Davis and Lees, &c.

[The true moraine of the ice-sheet is then at Skipton, while a local tongue extended to Bingley, and local lakes covered Bradford and the valley east of Skipton.

Immediately south of Ilkley, and west of the Cow and Calf, is a remarkable assemblage of detritus, made of huge angular blocks of sandstone imbedded in clay; heaped in great masses like a local moraine; not rounded except in the stream. Can it be a local moraine pushed out by the Aire glacier, or is it only detritus? There is nothing of the kind on the north side of the Wharfe. It is heaped up in hummocks much like a moraine. The boulders are not scratched—i.e. I could not satisfy myself that they were. The weathering of the false-bedded sandstone makes an appearance resembling glacial striæ. After thinking that it could not be a moraine, I found on top of the cliff, at a quarry where the sandstone had been recently bared, distinct glacial striæ running parallel with the valley here, and coming from the west, up the stream, as was proved by the tails behind the pebbles.

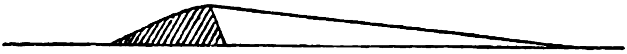


FIG. 33.—Quartz Pebble with a Sand Tail.

I have no compass, but the striæ go toward the east. The till is very loose and sandy, more like atmospheric detritus, and seems to be made of sandstone solely.

Striæ are seen on a number of rock surfaces here. Also some beautifully symmetrical round pot-holes in the sandstone, measuring 2 feet or more in diameter.

These are between the two quarries which are just west of the Cow and Calf. On an adjoining surface are some curious rock inscriptions.[1]

Perhaps the pot-holes are aboriginal grain mills. Similar pot-holes occur at the 'Cow,' and seem to be due to the weathering of soft concretions in the sandstone. Possibly the 'Calf' has been pushed off by the glacier. Grand view.

Observations on the rock just south of the Cow lead me to think that the aboriginal drawings given above are *natural*. The face of the rock weathers in this peculiar way.

I see more of these cups and rings on large boulders high up on the moor.

The eskers or sand banks on top of the moor are known as Laneshaw Delves, and limekilns have been built upon them.

They are heaps of stones. One great moraine heap on Burley Moor is called 'Skirtful of Stones,' as John Lancaster, a shepherd on Ilkley Moor, tells me. The Laneshaw Delves are thought to be entrenchments, and are all made of loose boulders, &c. Some of the sand heaps are held to be 'Roman camps.' Small pebbles of limestone occur on Ilkley Moor, and a ridge of moraine stuff lying east and west just behind Ilkley, extends to near Silsden; it is clearly a *moraine*. A tarn or small pond is in the moraine back of Ilkley, but recent improvements in enlarging the tarn have obliterated its natural origin. We have here clearly a great moraine around the glacier of Rumbles Moor.

This moraine has been held to be the result of early British works. Thus 'Laneshaw Delves,' 'Little and Great Skirtful of Stones,' 'Long Ridging,' &c., are all probably parts of the moraine (see *Guide to Ilkley*). The moraine on which Upper Ilkley stands, and which, I believe, has not been described, is well worthy of a visit, and bears a close resemblance to an Alpine moraine, being much more full of large angular blocks than the moraine of the ice-sheet.[1]]

---

[1] See paper by Holmes, *Yorks. Geol. Soc.*, 1886.

Burley, Ripon, and Harrogate

[At Burley are fine heaps of till often containing large glaciated boulders, and much drift is here filling in the valley. At Otley there are grass-covered hills containing boulders which seem to be drift, heaped up like a great moraine. Drift appears to continue to Pool, though on account of the grass I cannot be sure. Rocks outcrop at Pool. At Arthington there is nothing definite, but that the Wharfe is in a broad, low, drift-filled valley. No signs of glaciation are seen about Pannal, though the soft, black carboniferous shales make grass-covered slopes not easy to distinguish from drift. Between Starbeck and Harrogate we cut through a deposit of sand and boulders, and at the north end of Harrogate we enter a deep deposit of till[2] full of boulders. I get out to examine this. I find Hig' Harrogate built upon clayey till, full of boulders and fragments, sharp, glaciated, and rounded.

I find pebbles of fossiliferous carboniferous limestone here, and in the railway cutting a boulder of red granite. Many boulders in the long railway cutting at High Harrogate are glaciated. Below the till is loose sandstone, which is striated to E.N.E. This is uncertain because it may be only a large striated boulder, and probably is such.

(Harrogate has sulphur springs.) I find in a cutting of the railway the cast of a fossil lamellibranch.

From Harrogate I go to Ripley. A large mass of drift, full of boulders and very deep, is cut through between Nidd Bridge Station and Wormald Green.

Just below Wormald Green, drift 20 feet deep lies upon the limestone. The limestone (permian magnesian) is said to be glaciated. Just above the station are large quarries and limekilns, and the rock is cut by the railway. We are clearly in a glaciated district. Hummocks of drift occur at Ripon, and the railway here makes a deep cutting through red sandy morainic (?) drift overlying soft red sandstone. The Ure Valley is choked up with drift. I continue northward. There is very flat country to and about Melmerby Junction, and it gets still flatter beyond near Baldersby, Topcliffe, and Thirsk Junction. At Thirsk Junction is rounded gravel.

---

[1] For the moraines on Burley Moor and Hawkesworth Moor see *Survey Memoir*, 92 S.E., p. 12. They begin south of Ilkley at 1,175 feet, and go east, and then south to Hawkesworth, &c.

[2] *The fringe.*

Was the moraine at Ripon?

From Thirsk I go to Darlington. It is level from Thirsk to Northallerton, where hills arise, consisting in part at least of boulder-bearing drift. They are not hummocky, but are smoothed, as if by water, their longer axes being parallel to the railway. The exposures are unsatisfactory. The hills continue, often containing boulders, to near Dalton Junction. One mile above Dalton Junction hummocky moraine-like hills occur, heaped up and high. These are seen till we pass Croft Spa and must be examined. Deep drift is found at Darlington.

Great masses of drift are exposed at Darlington, especially at the 'Manfield Scar,' a mass of drift, while rock occurs both higher up and lower down than Darlington. Non-glaciated rocks occur at Northallerton, the hills being due to rock. The Durham road near Darlington passes along and over many hills of drift.

Bushel Hill, Harrogate Hill, &c., are all made of till. Borings at Darlington show the drift to be 300 feet deep. The moraine runs east and west parallel to the striæ.

There is deep drift on top of the limestone quarry at Aycliffe.]

Richmond to Knaresborough

[I go from Richmond to Pilmoor Junction and thence to Knaresborough.

At Brafferton, close to the River Swale (?), is a deep cutting (40 feet), through red sand and gravel. Level ground follows like a great *lake*, there being a dead level between the Swale and the Ure at Boroughbridge. Beyond Boroughbridge is a flat terrace of gravel and clay, which continues to Copgrove, where drift hills occur, particularly one third of a mile beyond, and this is possibly the moraine.

Uneven country follows with apparently deep drift. Between Knaresborough and Harrogate there is also apparently deep drift (moraine ?).

From Harrogate I go to Leeds. Above Pannal is a deep cutting through drift (?), rock having occurred above it.

It is probably not drift but soft shale.

Similar grass-grown sections occur to the south, and it may be that what I supposed to be drift about Copgrove is the same thing.

A driftless high region is seen just below here.

But fresh cuttings north of Leeds show boulders of sandstone on sandstone. Is this aqueous from the Aire?

It is the fringe; being a finger lake connected with the great lake, dammed up at the mouth of the Humber.]

Cleethorpes to Sheffield, Derby, and Shrewsbury

[West of Cleethorpes the coast is flat, and there are no cliffs, but in a deep excavation for brick-clay or fireclay I see—a tough dark clay. A level country continues to Ulceby, where it is flat to the north, but just south of the station the ground rises and clay is exposed, forming a bank in front of the cliff of the chalk wolds. Between Brocklesby and Barnetby we are in a plain of stratified drift, which extends north to the Humber and south to the chalk cliffs, half a mile to the south. A good exposure here shows chalk, capped by a stratified warp-like deposit some 4 feet thick. Flinty angular gravel is also seen.

After cutting through Kimmeridge clay, we again reach a low region covered by Hessle clay. This is the River Ancholme at Brigg, up which a long arm of alluvial silt runs. At Retford is soft triassic sandstone, with 2 feet of red gravel on the top. Wave action as on the Delaware River is seen. No Hessle clay is visible about Retford. Red soft trias comes often to the surface to the west of Retford, and the only drift is a thin gravel, very often absent. About Worksop the only signs of drift are a few pebbles, and west of here even these disappear, and no drift is seen on the permian limestone. The coal-measures are driftless. Sheffield itself lies in a deep hollow in the valley of the Don. Erratics have been drifted by ice-cakes up this valley. South of Sheffield I see no trace of drift of any kind, until we descend into the valley of the Derwent at Wingfield, where is a flat deposit of clayey, mostly local, fringe-like drift, and we are clearly entering a *lake finger* widening out into the open water at Derby. Even here the drift is a clayey alluvium, confined to the valley bottom, and the rocks on either side are free from drift. I see no trace of glaciation in this region, nor am I aware of any trace of marine conditions here. A lake dammed by a glacier would be icy cold. The valley broadens as we approach Derby, and is perfectly flat up to where its rocky sides rise steeply. At Derby we are in the valley of the Trent, a tributary of the Humber. On examining a cutting at Derby I find a loamy gravelly clay in which the stones are well rounded. I call on Mr. Deeley, whose paper on the district, *Q. J. G. S.*, 1886, see. He is mistaken in thinking land ice came here. Doubtless the lake was frozen on top.]

York to Manchester

[After leaving the plain of York, we cross the region of the permian limestone, and observe many exposures but no drift. An excellent exposure of carboniferous shales, quite fresh, occurs at Normanton and beyond, showing rock running up to the surface, where it is decomposed, and having no drift on top. There is a good similar exposure at Wakefield, and another at the tunnel near Horbury

Junction. No drift is seen at Thornhill; quarries of carboniferous sandstone are there. There is no drift in the valley of the Calder (see papers by Davis and others on the Calder. Davis is right in his explanation of the drift at its *mouth*). No drift at Mirfield. There are quarries here and exposures are on the railway. The exposures at Brighouse Station show no trace of drift. Ditto at Elland. Ditto at Sowerby Bridge (fine exposure here). We keep up the Calder to Hebden Bridge, where still no trace of drift is to be seen. No drift at Todmorden or Walsden. On the west side of the mountains going to Manchester, viâ Rochdale, no exposures are seen until we approach Manchester, where till abounds. The hills about Castleton look extremely like hills of till, as do all the hills from Rochdale to Manchester. Cuttings at Manchester show a clayey till. In Peel Park, Manchester, is a large boulder of granite, weighing about six tons, similar to the granite near Ravenglass on the coast of Cumberland. It was found in the gravels at Stony Knolls, Broughton, according to the description placed on it, and was afterward removed to Peel Park, Manchester (vide *Heywood's Guide to Manchester*, p. 23).]

NORTH LANCASHIRE AND CHESHIRE DISTRICT

REFERENCES

Proceedings of Manchester Geological Society

E. W. BINNEY, Notes on the Lancashire and Cheshire Drift, December 1842. *Annual Report for* 1843, p. 15.

Shells were found by Mr. Harkness in till (*2) near Ormskirk; also in the cutting of St. Helens Railway two miles north of Runcorn.

The drift is divided into 4. River gravel and sand
3. Gravel and sand
2. Till — Glacial
1. Sand and gravel

In the sand on Kersal Moor is a mass of till entirely surrounded by sand and gravel. Near Black Moss, above Ramsbottom in Walmersley, and at Pikelow near Macclesfield, the drift goes up to 1,000–1,200 feet. Some of it probably passed Todmorden by the valley at Littleborough, the highest point of this valley being 610 feet above the sea.

E. Hull, On the Occurrence of Glacial Striations on the Surface of Bidston Hill, near Birkenhead. *Trans. Manc. Geol. Soc., sec.* iv. 1862–3, p. 288. Professor Hull describes striæ 150 feet above the sea, and mentions two cases already described by Morton at Liverpool.

J. Aitkin, Glacial Action near Clitheroe, v. p. 84. One mile north of Clitheroe, at Salt Hill Quarry, is a channel with striæ going NN.W. and SS.E., the rocks being worn away to the north. The drift is full of limestone from the north. Thick beds of gravel occur four miles north-east of Burnley, on the slopes of the valleys of Swinden and Thursden; this gravel is so charged with limestone boulders and pebbles that it has been washed and burnt for lime. [Moraine ?] Striæ are nearly north and south, perhaps NN.W. and SS.E.

Binney, vi. p. 76. Shells at Bowdon, Blackpool, St. Helens, Runcorn Gap, Ormskirk, traces near Kersal Moor, and in the gravel at Tintwhistle; none have yet been found at Manchester. None at Bacup. Vi. p. 76, Aitkin says till goes up to 700 feet at Ramsbottom, and to 1,100 feet about Bacup.

Aitkin, vii. 16. At Chatburn are striæ near the railway station going SS.E. Vii. 36, a thin bed of drift is at Holcombe Hill at 1,150 feet. Porphyry, grit, syenite, granite, &c., occur here, being the highest drift deposit of the neighbourhood.

J. Plant, vii. 40. On the Glacial Groovings on Bünter

Sandstone at Ordsall Clough, Salford. Boulder clay lies directly on the groovings, and is 10 feet deep; elevation 96 feet.

Ordsall Clough, Salford . . .	N. 40° W.
Park Hill, Liverpool	N. 42° W.
Bidston, Liverpool	N. 30° W.
Kirkdale, Liverpool	N. 15° W.

Most of the boulders are *limestone.*

J. Aitkin, Outlier of Drift Gravel on Holcombe Hill. The drift is an isolated outlier, and does not occur either east or west of here at the same level, in both of which directions it dies away at 950–1,000 feet, ‘a mean level to which these deposits generally attain along the sides of the Irwell and its tributaries in this locality.

‘Hull found drift at 1,380 feet at Winter Hill.’ (*Mem. of Geol. Surv. of Bolton District.*)

Eccles, vii. 62. Striæ at Mellor between Blackburn and Preston. Direction is 10° to 12° N. of E. They occur near the base of the hill on its north-west side as if the ice was deflected. They occur also on Kinder Scout Grit, on a hill on which is a Roman camp.

Plant, x. 105. The granites of Manchester are from Eskdale, not Shap. Wasdale granite also occurs. The first is *red*, the second mainly white.

Binney, x. 116. Chalk flints occur at Bugsworth, Vale Royal, and Bullstrong Common about Crewe.

Kerr, x. 116. Traces of Glacial Phenomena in the Valley of the River Irwell and its Tributaries in Rossendale. Drift occurs here in the troughs of the valleys, thinning out as one ascends. It consists of limestone, chert, greenstone, a few granitic pebbles, &c., generally all *small.* On no portion of the rock *in situ* has any trace of striation been found. *Mounds* are described and supposed to be moraines, 550 feet ± at Rawtenstall to 820 feet at Bacup. The drift reaches up to nearly 1,000 feet, as in Sommey valley below Newlaith, on the slope of Hambleton, and at Scar Burn.

J. Aitkin, xiii. 133. High-level Drift near Bacup. Drift pebbles, including flint, occur on Hornecliffe Moor at 1,060 feet. Near Bacup, on Brandwood Moor, 1,250 feet, are boulders of silurian grit, syenite, and quartzite embedded in a matrix of coarse sand derived from the local rock. A large mass of drift occurs in the Corm and Shawforth valleys below.

On Bull Hill, north of Holcombe Hill, at 1,371 feet, are pieces of volcanic ash and quartzite grit, agate and flints. (Agates occur near Ireleth in Furness.) The flints were chipped and perhaps carried by man. On the top of Cribden, overlooking the Irwell at Rawtenstall, at 1,300 feet, is a small volcanic-ash boulder. At the top of Ousil Clough, near Crawshaw Booth, on the moorland between Cribden and Hambleton, at 1,100 feet, are drift pebbles of syenite, granite, felstone, limestone, &c. Also near the summit of Dirpley Hill, at 1,370 feet, is a boulder of chert. At Higher Stack, one mile south-east of Bacup, is foreign gravel at 1,110 feet.

All this is held to be due to an ice-sheet passing over the whole region.

Aitkin, xiv. 53.

R. D. Darbishire, Notes on Various Shells found in Stratified Drift near Macclesfield. *Mem. Lit. and Phil. Soc. Manchester*, 1864-5.

Hull, Green, &c., Geology of Burnley Coalfield.

Drift is 170 feet deep on the Ribble, near Balderston Hall, below Ribchester, where upper till, middle sand, and lower till are to be seen.

Upper till, 55 feet .	Red laminated clay
Middle sand, 50 feet .	Red sand
Lower till, 10 feet .	Stiff clay with angular pebbles

Deep drift lies to the north and west of Blackburn. Clerk Hill, near Whalley, is covered by drift at 500 feet. Till at Brinscale, east of Chorley (railway cuttings), contains limestone, but no Lake District erratics and no shells; it forms a boss, *overlaid* by boulder clay and sand, in which are Lake District erratics. There is a sand mound at Leyland. Knolls of sand are common north and south of Chorley, between Leyland and Farrington, and one lies on the road between Blackburn and Preston. Large patches of sand occur at Preston, Kirkham, Chorley, and Leyland. Shells are at Preston, Red Scar, and Tun Brook, and the mounds between Chorley and Heapy are possibly eskers (p. 151).

De Rance, Glacial Phenomena of West Lancashire and Cheshire. *Q. J. G. S.*, 1870, p. 641.

Much of the boulder clay and sand in the lowlands here is marine. Mr. De Rance (p. 643) holds that the so-called lower till or boulder clay at low levels is marine, and rests on an eroded surface of very stiff, dense, non-fossiliferous till containing angular blocks of comparatively local origin and due to glaciation. He says, 'I myself have never seen any marine lower boulder clay above the elevation of 150 feet, indicating a glacial sea in the Lancashire lowlands not deeper than 25 fathoms.' [His lower marine boulder clay must correspond to that at Montreal.]

The stiff blue lower boulder clay, the true till, rises high up on the sides of the mountains.

Over this is the sand and gravel of the middle drift, with transported [?] shells, indicating an amelioration of the climate.

Over this, again, is the upper boulder clay, which 'resembles in the whole of Lancashire the lower boulder clay of the southern part of the *low country* (i.e. the marine clay) in its physical character, chemical composition, included erratic fragments, and species of shells of mollusca found with it.' [It is clearly the same deposit made at the same time, p. 648.] 'Both clays contain more Silurian erratics in the north-west and more carboniferous erratics in the south-east of Lancashire,' and are of the same dull red colour, which colour, as Hull deems (*Geology of Country around Oldham*, p. 48), is perfectly irrespective of the rocks upon which it may lie, being nearly the same when it occurs on the Silurian, Carboniferous, Permian, or Trias. [It is then clearly *marine* ?] Both clays are sometimes stratified; the base of the 'upper boulder' clay is often a bed of marl containing glaciated stones [being thus similar to the *'marl' of Wexford*]. The esker drift is much more *local* than the middle drift or boulder clays in the origin of its pebbles [i.e. it is due to the melting ice]. The esker drift, as Mr. Strahan (*Q. J. G. S.*, 1886) has shown, rises up from *beneath* the marine clays in North Wales and Cheshire. Mr. Binney holds the upper and lower boulder clays of Hull to be identical, and one deposit with sand occasionally interpolated in its midst.

[I cannot agree with the interpretation that Mr. De Rance gives. His successive elevations and depressions and alternations of climate are at variance with facts observed in the east of England or in glaciated areas.

The clays and gravels of marine origin were made partly as the ice was advancing, partly as it was retreating, when the sea, 150 feet or more in depth, was washing against the ice-wall, and was covered with floating rafts of ice. The sea was not an arctic sea, as the shells show (*Turritella communis, Purpura lapillus, Cardium edule, Tellina balthica* being the most common).[1]

Most of the clay visible was, of course, made as the ice was retreating (?), the earliest clays and sands having been eroded or carried forward by the ice-sheet and the shell-fragments left in its terminal moraine high up in the mountains. While the ice was at its maximum extension and had shut out the sea, subglacial freshwater streams made the eskers, which were partially buried in the lowlands by the marine boulder clays formed after the retreat of the ice.

---

[1] These shells are precisely those which are commonest at Craike Hill and at Kelsey Hill in Holderness. Is it not possible that here, as there, there was a submergence, during the advance of the ice, of 100 feet to 150 feet only; and that the shells at higher levels and in the till are re-arranged? The shells from the drift that I have seen from Lancashire are much worn, as if transported. If the sea was 150 feet deep during the advance of the ice, they could easily be pushed up to Moel Tryfaen, Macclesfield, and elsewhere, and in either case would have to be transported less than a mile.

This I believe now (November 16, 1887) to have been the history of Lancashire during the Glacial Epoch.

The *post-glacial deposits* of the same region are described by Mr. De Rance in *Q. J. G. S.*, 1870, 655, and its *pre-glacial* elevation is indicated by Mr. Reade (*Proc. Liverpool Geol. Soc.*, 1872–73, p. 42).

North-east of Southport there was, before it was drained in 1692, a large mere called Martin Mere, which was dammed in by a ridge of drift (*l. c.* p. 664).

As Greenland rose higher than now, so did Lancashire after the Glacial Period (200 feet [?][1] to 300 feet [?]); and Ireland was then connected with Wales at St. Davids, so that man and mammals could migrate. It is now subsiding, as is Greenland (Brown, *Q. J. G. S.*, 1870, 682) and Eastern America.

C. E. De Rance (Superficial Geology of South-west Lancashire, &c., 1877) gives a list of striæ in twenty-two localities. He says (p. 48), speaking of the 'middle sands':—'Everywhere the current bedding of the sands is in a south-east or east-south-east direction, proving the existence of great north-westerly tidal currents.' [What does he mean? Are these due to subglacial streams flowing *backward*?] 'Beds of the age of the middle sands and gravels in Cumberland, North Wales, and Derbyshire rise from 1,200 to 1,500 feet.' 'Produced by action of breakers upon successive lines of coast.'

Mr. Kerr (On Traces of Glacial Phenomena in the Valley of the River Irwell and its Tributaries in Rossendale) describes many drift *mounds* [*the terminal moraine*] which occur at 900 to 1,000 feet. This must be near *Bacup* (*Trans. Man. Geol. Soc.* x. 116).

---

[1] What is evidence of this 200 feet rise?

For the geology of Cheshire consult Ormerod, 'Geology of Cheshire,' *Q. J. G. S.* vol. iv. p. 262.

E. Hull, in *Geology of the Country around Altringham, Cheshire* (description of map 80 N.E.), speaks of the abundance of 'little lakes or meres'[1] in hollows in the drift.

One of these is Rosthern Mere, 100 feet deep, lying in boulder clay. [This looks like moraine lakes.] Bowden, High Leigh, Tatley Hill, &c., are all in the drift.

Ormerod (*l. c.*) explains these kettle-holes curiously, suggesting that the rain has dissolved away the salt in spots in the underlying red marl (which contains beds of rock-salt), and that thus the gravel sank, making the hollows. He thus explains Budworth Mere and Pickmere, which are north of Northwich.

The drift is very thick about Manchester. The banks of the Irwell at Whitfield are made entirely of drift, 140 feet high; at Prestwich, drift is 150 feet thick; at Kersal Moor, 160 feet; about Ashton, 174 feet, &c. (Hull.)

Binney, Notes on some High-level Drifts in the Counties of Cheshire, Derby, and Lancaster. (*Proc. Lit. and Phil. Soc. Man.* Read 1870). Describes erratics at 1,000 to 1,400 feet.

Binney, Sketch of the Drift Deposits of Manchester and its Neighbourhood, with maps (*Lit. and Phil. Soc. Manchester*, vol. viii.). The drift, he says, is in three members: the lowest is a soft sand, often absent; then a true till full of striated pebbles; and on top is a white sand and gravel, with marine shells, driftwood, coal, and rounded pebbles, this latter high-level gravel forming outliers in the plains of Lancashire and Cheshire (Hull, *Geology of Altringham*, p. 6).

The drift of Manchester. Here are valley gravels, till full of striated stones, sand, &c. Till is thick under Manchester. It effervesces with acid. The boulders come from the north and north-west of Manchester. Many lar are described, often striated. He thinks the till at chester, which is often stratified, was made by wate icebergs, while glaciers existed in the Lake Distric the north of Lancashire. He thinks many of the s and polished rocks may have been made by *floating of ice*, and that, as the land was elevated and the shoaled, the neighbouring glaciers would melt and b down beds of sand and gravel to cover up the till.

---

[1] Is not 'mere' a good word for glacial small lakes? A pond is artificial, but a 'mere' is a natural pond.

Especially large numbers of boulders are in the till Broughton and Collyhurst [medial moraine?]. Hill occur on Kersal Moor. Railway cuttings are given p. 221.

Manchester and Vicinity:

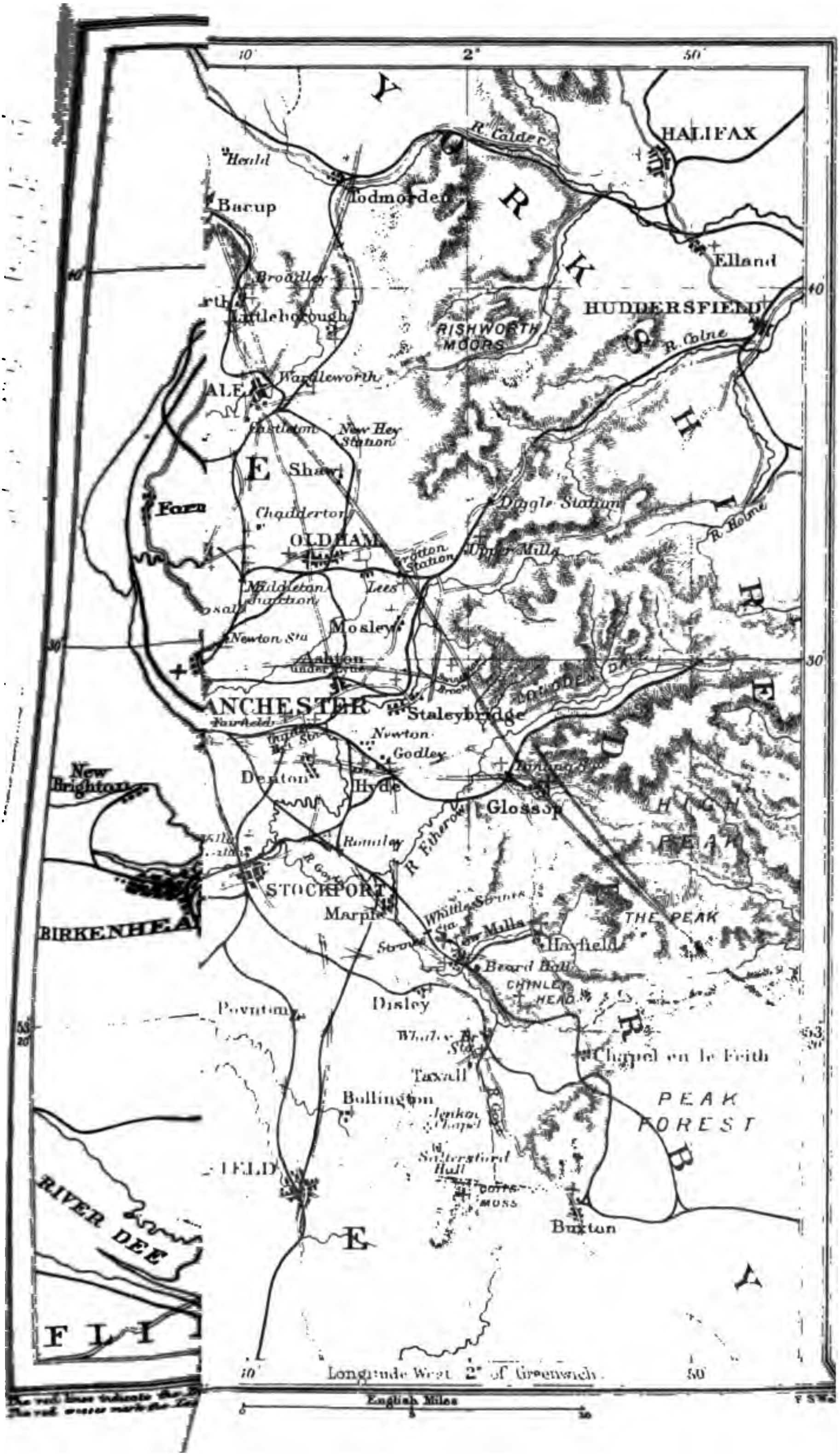
Hyde, Marple, Rochdale, and Bacup

[Drift is abundant about Manchester, and deep morainic hills occur just north of the town. Cheetham Hill is a mass of drift, consisting of alternating clays and gravels. If, as Hull, Geikie, and others have imagined, a sand between the boulder clays represents an interglacial period, there is evidence on Cheetham Hill of five glacial epochs. Deep drift goes northward to Bury; but it seems that there is a line of drift hills, often sandy, extending to the north-west, like a medial moraine.

I notice large drift hills, mainly of sand, about Clifton Junction and north-west of here.

Is this a medial moraine dividing the glacier which came along the Irish Sea west of Black Combe from the ice which came across the Lake District east of Black Combe?

I go to Hyde, where the drift is deep. At Godley Junction, east of Hyde, is a cutting through a hill of sand. Deep drift hills also occur about here. The stiff till at Hyde contains many hornblendic rocks from Scotland, and many of the boulders are glaciated. Granite, quartz, felsite


Y O R K S H I R E
HALIFAX
R. Calder
Heald
Todmorden
Bacup
Elland
Broadley
Littleborough
HUDDERSFIELD
R. Colne
RISHWORTH MOORS
Wardleworth
Castleton
New Hey Station
Shaw
Chadderton
OLDHAM
Diggle Station
R. Holme
Grotton Station
Upper Mills
Middleton Junction
Lees
Newton Sta
Mosley
Ashton under Lyne
LONGDEN DALE
ANCHESTER
Fairfield
Staleybridge
Newton
Godley
Denton
Hyde
Glossop
HIGH PEAK
R. Etherow
Romiley
R. Goyt
STOCKPORT
Marple
Whittle Strines Sta.
New Mills
THE PEAK
Hayfield
Strines
Beard Hall
CHINLEY HEAD
Disley
Poynton
Whaley Br. Sta.
Chapel en le Frith
Taxall
Bollington
PEAK FOREST
Jenkin Chapel
Saltersford Hall
GOYTS MOSS
Buxton
FIELD
E
Y
New Brighton
BIRKENHEA
RIVER DEE
F L I
Forn
ALE
rth
osal
10'
2°
50'
40
30'
53° 20'
Longitude West 2° of Greenwich
English Miles
0
5
10
The red lines indicate the
The red crosses mark the
F S W

occur here, as described by J. Lomas (*Proc. Liverpool Geol. Soc.* v. 1886–7). A fragment of a pecten was found here by Mr. Kendall, and Mr. Lomas found serpentine (from Galloway?). A boulder of serpentine was also found in the Isle of Man.[1]

I go to Marple, finding an abundance of drift, west of the town and at the railway station, banked against rock. No evidence of glaciation is seen farther east as I walk toward Strines; the rocks are non-glaciated. On reaching Strines Station an exposure of clay, containing many well glaciated boulders, sharply striated is seen. Are we here on the fringe? The River Goyt flows west towards the Cheshire Plain. The drift at Marple Station lies upon rock, and is not a moraine, as I formerly thought.

I go to Oldham, north of which is deep drift. At Shaw, I walk eastward to the coal measure rocks, but find no trace of glaciation, although *finger-drift* lies in the valleys.

The moraine lies west of Shaw, but the fringe extends up valleys to the east of this locality.

At New Hey is a deep deposit of till, full of boulders; the moraine.

I go to Rochdale, and find at the junction east of that place and at Wardle deep deposits of drift. Wardle seems to be built on the moraine, which is seen in a railway cutting at Wardleworth and north of the station.

On the railway to Bacup we cut through the moraine distinctly between Broadley and Whitworth. Fine moraine hills full of boulders of granite, &c., occur here, the erratics projecting from the bank.

North of Whitworth the fringe is seen. It makes a level-topped deposit of clay and stones in the valley of the stream, which latter flows towards the moraine. The extra-morainic lake extended up to Facit, above which I notice no drift, and we are clearly here in the non-glaciated area.

---

[1] This is recorded by M'Culloch, but the specimen has never been duplicated. Mr. Kendall, who has examined hundreds of boulders in the Isle of Man, has never found a serpentine.—H. W. C.

At Bacup are hills of drift on the south side of the town. They are hills of fringe drift, composed of clay containing rounded stones, mainly local sandstone, but also sometimes Lake District ash and other rocks.

I took an excursion party from the British Association to see this exposure of fringe drift, just outside the moraine.]

Kersal and Swinton

[I take the train to Higher Broughton and Kersal.

At St. Paul's Church, Kersal, I see typical moraine mounds; and on Kersal Moor is as typical a moraine as one could find. Round hummocks are interspersed with saucer-like hollows. The high gravels here are made mainly of sand and coarse gravel, in which are layers of clay. I call the pebbles erratic pebbles—being in great part Lake District felsite, felsitic ash, coarse red Eskdale granite, and an occasional chalk flint. These are the same hummock-like hills that I saw at Heaton Park, and Crumpsall, and Cheetham Hill. I found one erratic of black limestone, but only one. Striated stones were also found.

The hummocks lie in a series of parallel ridges, each of which trends about S. 60° E. (magnetic) or S. 74° E. (true). Are these parallel or at right angles to the ice motion?

I cross the river and go to Pendlebury, where at the corners of the streets are many boulders, over a foot long, of granite, Lake District felsite, &c.

Near Swinton Station is a boulder of granite, 3 feet × 2 feet × 2 feet.

Morainic hills are seen north of Pendlebury. At Swinton Station is a brickyard exposing 12 feet of tough gray boulder clay, full of erratics of granite, felsite, quartz-porphyry, &c. Many of the shales, &c., here are striated. There is a large proportion of granitic and quartz-porphyry boulders here, as there is about Glossop, New Mills, &c.

The Lancashire and Yorkshire Railway cuts through deep boulder clay at Pendlebury (30 feet), no rock appearing. All this seems to be morainic drift.]

Worsley

[I take the London and North-Western Railway to Bolton.

At Cross Lane Station, behind a brick wall, a fresh exposure of 20 feet of tough boulder clay is seen. Red sandstone comes to the surface about Eccles. Flat ground follows; but just about Worsley Station we suddenly enter deep hills of drift, both sandy and clayey, being sandy at first, and farther on till. Large erratics, often striated, occur in the cuttings, which are 40 feet deep—clearly in morainic till. There are more cuttings through sandy and clayey drift north of Walkden Station and about Little Hulton, where the drift is deep. This is on high ground, 200 feet above Manchester. At Plodder Lane sandstone comes to the surface, with only a few feet of drift on top. It is true glacial drift, however, not a clay. Heavy drift, full of sandstone boulders, occurs south of Bolton.

I return to Worsley. Above the station the cuttings are in sand. Near the railway crossing, imbedded in the side of a cutting, is a large boulder of granite, measuring as exposed, 4 feet x 3 feet x 2 feet, and perhaps larger; it is finely striated. The striæ are parallel to its longer axis, pointing as it now lies W.N.W. and E.S.E. It is a white, micaceous, coarse granite, probably from Criffel; and is the best example of a glaciated granite erratic I have seen in Lancashire.

North of here the cutting is in clayey till; pebbles of hornblendic granite, felsites, and limestones, are common. There is much carboniferous limestone here, a circumstance in which it differs from the drift at Glossop, New Mills, &c., to the east of this place.

On the main road, close to a bridge crossing the railway, are two fine erratics, each a yard or more long; one is of Criffel granite, the other of felsite, and both are well glaciated; the striæ being parallel to the longest diameter. I examine a gravel and sand pit north of Worsley. There is coarse washed morainic drift below, characterised by a quantity of granite and limestone pebbles, overlaid by sand and laminated clay, 10 feet deep.

About Worsley, lying at the edge of the road, are a number of well-glaciated boulders. Two of Criffel granite, 3 feet long, are near the Bridgewater Canal; others of felsite, some 2 feet long, are near the Bridgewater Hotel—all being striated and polished.

Carboniferous sandstone unglaciated (?), with no drift on top, outcrops in Worsley at the canal and near the church: there is clearly no moraine here. I go to Walkden, where drift with boulders of granite, 'Buttermere' syenite (a quartz-porphyry) again appears.

Brickyards here show clay on top, then a boulder clay, and underneath sand resting upon very coarse glacial gravel.]

Manchester to Heaton Park

[From Manchester I go to Heaton Park. We cut through deep masses of drift immediately on leaving the station, and continue in a series of rounded drift hills to Crumpsall, which is built on them. I walk through Heaton Park, where morainic hills are beautifully shown in soft rolling knobs, enclosing occasional moraine meres. These hills extend for at least a mile through the park. Red granite is abundant; limestone pebbles likewise abound; also green felsites, &c.

Deep drift is seen about Prestwich.

From Staleybridge northward to the West Riding, east of Manchester, the railway cuts through deep drift, and rounded drift hills occur west of Ashton.

From Staleybridge I go northward to a road leading east from the Huddersfield Road, up the Swineshaw Valley. Clayey drift is here heaped up in low moraine-like mounds, covering over the carboniferous sandstone. At a sandstone quarry, 400 feet above Manchester, drift lies 15 feet deep upon the rock, and is a clayey till full of scratched erratics, including felsite, Eskdale granite, Buttermere syenite, picrite, and carboniferous limestone.

Near the great reservoir are hummocks made entirely of loose drift. A section in one of these shows it to be made of boulders and loose drift at least 50 feet thick. On the north side of the valley, the moraine (lateral) as it rests against the mountain is finely shown; the drift being distinguished by green fields, the mountain above by brown vegetation. The drift makes a well-marked terrace on the side of the mountain, as is seen on looking northward from the lowest reservoir. The reservoir is made in the moraine, as is so commonly the case.

Was a mere formerly here?

I climb up the mountain, going east with the road, and soon getting east of the drift. At the highest of the reservoirs there is no drift of any kind. But at 800 feet above Manchester are some pebbles of Lake District granite and felsite. Exchange Station (Manchester) is about 120 feet above the sea.

The moraine at Staleybridge, while perhaps without characteristic topography, is a large mass of drift.

Rock with no drift is often exposed on the way to Greenacre.

Here the soil is made of broken carboniferous sandstone with no rounded pebbles. I now take the train for Oldham.

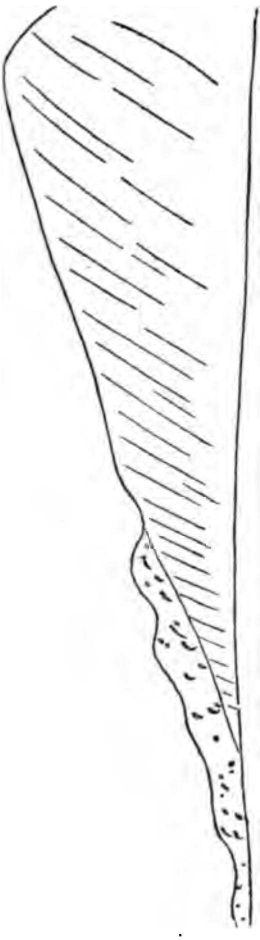


FIG. 34.—Moraine on North Side of Swineshaw Valley.

We pass through rock and then a long tunnel, and emerge at Grotton in what seems to be a very large mass of drift, heaped up like a great moraine against the west side of the mountain. Although rock appears west of Grotton, drift lies upon it, and at Lees there is much drift. Rocks again occur still farther west, but there is drift upon them, and it is seen at Oldham in abundance.

The moraine is at Grotton, banked up on the side of the mountain.

From Oldham I go to Rochdale and Todmorden. Drift continues northward, and is piled up in large moraine-like (?) hills at Shaw, south and east of the station.

These hills are very large, and the moraine is here finely developed. (Examine these to see if they are till, for I suspect them to be rock, as rock occurs between here and New Hey.) Drift full of large erratics is cut through at New Hey, where it is seen resting upon rock just north of the station. Much of this, perhaps, belongs to the moraine, whose eastern front cannot be far from here.

At Rochdale I turn east. We cut through rock without drift before reaching Smithy Bridge. No drift is seen beyond here.

Littleborough is driftless, the hills all being rock.

The moraine seems here to be a few miles away from the mountain, and Rochdale is, perhaps, at the edge of the non-glaciated area, and just outside of the moraine. I see no drift at all between Rochdale and Todmorden. There are bare, unglaciated rocks at Walsden and Todmorden. I now take the train for Burnley, going north-west.

Cornholme is driftless, ditto Portsmouth. I go on farther. Immediately beyond Burnley drift appears,[1] and it is deep and full of large erratics of limestone, &c., at Rose Grove. The moraine, therefore, passes Rose Grove.[2]

The drift extends to Burnley, and at Hopton, the next station, we see rock with a thin covering of drift, and more drift at Huncoat.

I now turn back, going to Skipton viâ Colne. The moraine, if it is such, seems to run on the south side of Rose Grove.

---

[1] The drift at Burnley is mentioned by J. W. Davis, *Yorks. Geol. Soc.* vii. 141. 'On the Source of the erratic Boulders of the Valley of the Calder.'

[2] No. The moraine is east of Burnley. (Map VII., p. 188. - J. F. L.)

There is much grass at Rose Grove, and also on the sides of the deep cutting at Henley Barracks, so that I must not speak absolutely about the moraine here.

Just before reaching Brierfield, the first station beyond Burnley, are grass-covered hills of what looks like drift.

Seeing a fine exposure in a brickyard at Nelson, I get out to examine it, and find a clayey till full of well-scratched boulders of limestone, sandstone, &c., some 5 feet long, lying on a soft, disturbed, carboniferous fireclay or decomposed rock, which latter is dug for bricks. (The clay is ground, and then compressed by steam into brick moulds.) The hills about Foulridge are made of rock, but drift also occurs, filling the hollows, and thinly covering the hills. There is no moraine about here. No piles of boulders are in the fields. At Thornton limestone is exposed in a quarry on the west side of the railway, and the limestone is *smoothed off on top* as if glaciated. It makes a good anticlinal.

Heaps of till occur about here.

At Elslack Station is a good section of till freshly exposed. For the most part all the cuttings are so grassed over that it is impossible to learn what is beneath the surface. Above here huge mound-like hills of till, full of large limestone boulders, occur, and this has all the appearance of a great moraine. Till abounds at Skipton.]

The *Memoirs, Geological Survey*, 'On the Geology of the Burnley Coalfield,' by Hull, Dakyns, Tiddeman, &c , 1875, contain an excellent description of deposits which are clearly the terminal moraine.

P. 128. On Black Hambleton and Boulsworth erratics go up to 1,300 feet. [This is because the glacier came up to that height on the west side of the Pennine Chain.]

Above this height erratics and rounded boulders are absent, though both on Pendle, Boulsworth, &c., sharp fragments of millstone grit occur.

P. 131. The gravel is in *conical mounds* and hummocks, and 'these have somewhat the appearance of old glacial moraines.'

In the Valley of Hurstwood Brook, near Worsthorn, is a good example.[1]

The north bank of shale and flags is an 'original sea-cliff,' against which the gravel has been deposited. The gravel is worn into a great number of mounds. Similar appearances are in Thursden Clough, near the new bridge, in Swain's Platt Clough, along the higher part of Catlow Brook, and the upper part of Cant Clough Beck. At another place in Thorny Bank Clough, deep deposits of drift are banked up against the high escarpment of Hopton Scart, and are spread over the Lower Park. Here are hummocks, and we find 'a space of ground dotted over with conical mounds, like a colony of gigantic ant-hills.'

P. 132. Drift is abundant in the valleys of Catlow, Thursden, and Swinden Brooks, where are lime-kilns for burning limestone erratics. In Cant Clough Beck, at 1,000 feet elevation, are many lime-kilns.

The erratics are generally well glaciated. On these western flanks of the Pennine Chain drift is often 150 to 200 feet thick, while it is absent on the Yorkshire side. If an ice-sheet, the reason is (p. 133) that 'it is only on the west side that the Cumberland Mountains are found, and that it is on this side that the greatest amount of rain (or snow) fell, as at the present day.'

P. 133. Roches moutonnées occur as far south as the Pendle range, half a mile above Whalley, in the valley of the Calder; striæ go to S. 15° E. A glacial stream here went through a gap in the Pendle Hills [much of which must have been an island in the ice-sheet]. Striæ are also at Chatburn.

P. 134. On Horwich Moor (south of the margin of Blackburn one-inch map in 89° N.E.) are good striæ going

---

[1] Worsthorn is two miles east of Burnley.

E. 10° S. [Important when compared with the Liverpool striæ.]

Drift on the Pendle Range does not go higher than 1,000 feet. The rocks here are bent over toward the south.

P. 137. On the north side of Boulsworth gravelly drift and sand full of limestone boulders and mounds occur. Drift goes up to 1,200 feet, but not higher, on the north side of Boulsworth. It occurs three-quarters of a mile west of Lad Law, the highest point of Boulsworth Hill, and NN.E. of Red Spa. On the high ground south-west of Carleton it does not go above 1,050 feet, at Pack Head Quarry. The grit of White Moor and Carleton synclinal is free from drift, though much of this is between 600 and 1,000 feet in elevation. Even on the low ground there is often no drift. This is due to its *original deposition,* not to denudation [argument for its morainic origin]. No glacial drift is seen in the valleys east of Black Hambleton, Black Moor, and Boulsworth.

The lowest watershed here is 1,286 and 1,240 feet, which the drift could not surmount. But farther north, where the watershed is only 1,120 feet between Combe Hill and Crow Hill, drift has gone over the pass. It is very thick at Smithy Clough, and goes up to 1,050 feet. There is none on the watershed near Barn Hill nor in the Worth, but it occurs in the Worth Valley one mile and a half east of the watershed

[Perhaps then it did *not* go over the watershed, but came from the north, from Keighley.][1]

Till is very thick about Ickornshaw, 100 feet deep at least just north-east of the village. It is thick also at Laneshaw Bridge.

Mounds of drift are on the north side of Boulsworth, at Stack Hill, Smithy Clough, &c.

Mounds of gravel are on Ickornshaw Moor, and at Cowloughton, Emmett Moor, &c. [All this is the moraine.]

---

[1] Fringe.

Striæ on limestone west of Gill Church go S. 10° W.

There are mounds between Glusburn and Skipton.

Green, Russell, Geology of the Yorkshire Coalfield. *Memoirs, Geological Survey,* &c., 1878.

P. 775. The drift-covered area is divided from the nearly driftless area by a line following the watershed between the Aire and the Calder, as far east as Bradford Beck, and thence eastward through Leeds.

South of here there are certain glaciated areas, especially the one about Barnsley.

The elevation is about 150 to 200 feet on an average. Northern erratics of limestone, trap, &c., occur at Pledwick, 150 feet (two and a half miles south of Wakefield), Carleton, 140 feet (south of Pontefract), Norton Green (four miles north of Barnsley), 170 feet.

Royston Shap Fell granite boulders were seen here at 260 feet, east of Barnsley 120 feet, three miles NN.W. of Sheffield 480 feet.[1] Boulder clay extends from Barnsley to Carleton and Royston; it is full of erratics (150 to 250 feet).

[All the above are 150 to 200 feet, and are perhaps due to iceberg work, as the boulder clay is neither deep, nor continuous, nor hummocky.

But in the northern area, in the Wharfe Valley, Aire, &c., the till is as high as 1,000 feet, and full of limestone blocks, &c.

In Morton Beck the drift is 100 feet thick. This is due to a series of glacial tongues. East of Skipton the railway exposes a good section of till. Till covers the ground north of Silsden, and extends for a long way up the Worth Valley.

There is a deep cutting through drift on the railway between Shipley Station and Red Bank Mill, full of limestone, &c.[2]]

---

[1] This elevation is very doubtful, and is only evidenced by a sin le boulder which was probably carried up 100 feet.

[2] The ice-sheet clearly covered most of the ground between Burnley and Bingley. The northern part of Pendle Hill (1,831 feet) and possibly some

Glossop

[Between Manchester and Glossop are cuttings through deep drift, just beyond Fairfield; also just before Guide Bridge, also before Newton, where we rise to higher ground. It is a rolling hilly country, made apparently of drift, in part clay, in part yellow sand. At Godley is a fresh exposure of fine yellow sand, resembling the 'quartzose sand' of Deeley. Boulder clay lies on the top of this sand unconformably. The sand is hardened to look like trias. Beyond here are deep cuttings and two tunnels, through drift in large part, but before reaching Mottram we come to cuttings through carboniferous sandstone. Have we passed through the moraine?

Non-glaciated projecting rocks occur beyond Mottram. We now enter a wide open valley, and again cut through deep morainic boulder clay like that at Strines, being full of glaciated boulders; clayey and very deep, making a ridge, and apparently a moraine. Did a separate glacial tongue come down this valley?

At Dinting Station is genuine glacier-made stony till, resting upon rock. At Glossop is till, with boulders of granite and felsitic ash. At a sand-pit near Glossop till overlies false-bedded river sand. The till contains many large erratics of felsitic ash, and of red granite and syenite. These are often glaciated. A fine boulder of felsitic ash, measuring about 3 feet × 3 feet × 2 feet, and striated, lies embedded in till in the bank of a small brook close by. I find flints in the drift here. The sand and gravel are false bedded, showing currents *towards the north*, as if a river gravel, for the valley inclines northward. I find no traces of shells in the gravel, which is *not* the red fine sand seen at Godley, although coal fragments occur in it.

---

of the hills near Carleton existed as islands (the latter uncertain). The hill behind Carleton, which perhaps combed out the drift hills of morainic contour at Skipton Ingleborough (2,377 feet), must have been another island; Whernside also had projecting rocks, perhaps, but Bow Fell (2,216 feet) farther north was covered and crossed by the ice-sheet.

I climb up the mountain west of Glossop and find th the drift suddenly ends several hundred feet below the to The summit shows no trace of drift. On descending t other side towards the village of Simmondley, gravel wi pebbles of felsitic ash and red granite suddenly appea at an elevation of 500 feet above Dinting Railway Statio

Lower down large masses of till appear; and in t village of Simmondley, built on the moraine, are gre numbers of erratics. In the village a large collection granite, felsite, porphyrite, felsitic ash, and sandsto boulders, may be seen. It is the same collection as th about New Mills. Drift continues to Dinting. It looks as a glacier came from the north-north-west into this vall and passed southward to New Mills.]

Mosley

[We go up one side of the Tane from Staleybridge a down the other.

We go in the railway on the west side of the rive being in rock all the way, until we reach Mosley, whe there is deep drift near the station; but just beyond w again enter rock and keep in it, although great masses angular talus are cut through.

At Diggle we return to the new station, near the we side of the river, and go through rock, past Upper Mil Station, entering drift opposite Mosley, although it is n deep, and rock appears below. At Scout we cut through remarkable ridge of gravel at 470 feet, rising to at least 5 feet. This huge mass of gravel has filled up the who valley, so that the river has swerved to the west, and h been made to cut through solid rock. Marked on t Ordnance map as 'Kershaw Hev.' A very fine exhibition the *moraine*. It is made of coarse gravel and coarse sa partly stratified, like the lateral moraine of the Aar glac The stones are not striated. The moraine ridge r south-east, and can be seen lapping up on the mountain Swineshaw lower reservoir.] (*See* fig. 34, p. 261.)

[The river swerves round the moraine, and cuts into the rock by a post-glacial gorge. The gravel is filled with lake felsites, Eskdale granites, &c. The little church and cemetery appear to be on another mound of the moraine. No clay or till is here. I walk to Mosley, and thence to the top of Brown Edge, where are boulders from the Lake District at 950 feet above sea. On the west side of Brown Edge, at 800 feet, the boulders are numerous and large, and gravel is seen. Many of the boulders of granite and felsitic ash are 3 feet long. I go northward to Grotton Station, finding a quantity of boulders, and the valley deeply filled with genuine gravelly and yellow clay drift. Striated stones are very scarce.

The boulders are the same as those at Glossop, at Staleybridge, at New Mills, and at Taxall.

At Cover Hill brickyard, near Grotton, is a boulder of Lake District felsite, 5 feet x 3 feet x 3 feet, weighing two tons, well striated with striæ parallel to its length; and here also are numerous other striated blocks of granite, felsitic ash, &c., overlying coal shale. They continue to about the height of 870 feet; but higher up no large erratics are seen. At 1,000 feet are a very few foreign pebbles, but no erratics, and no drift occur on the sandstone.]

Ewood Bridge, Rochdale, &c.

[I go to Ewood Bridge and find here a typical moraine, composed of genuine clayey till full of erratics, often large and striated. Sandstone is the commonest rock; then come Lake District felsites and granites, being the same rocks as in the drift at Castleton. I notice no limestone. Moraine hills here fill the valley, appearing on both sides. I walk to Rawtenstall. At Newchurch drift is on both sides of the valley, rising high and full of granites, felsites, &c. The drift here is sandy and mainly full of sandstone. I climb up the hill to the south. At Rake Head Quarry is sandstone overlaid by till. The till is mainly filled with sandstone, but very occasional boulders of Lake District felsite and coarse granite occur. The sandstone is smoothed off, and I find striæ on it in three places. These point (magnetic) S. 48° E., S. 45° E., S. 50° E. The mean deep ends of the striæ are to S.E.

I see no limestone, and foreign erratics are scarce and small. This is a small tongue forced up Bacup Valley from the west. We rise quickly out of it.

The drift is deep and morainic here, but on rising higher up to the south we suddenly pass out of it and out of all drift, having sharply left the glacier. We are on a very poor road, which turned off between Newchurch and Stackstead Station. On the moor above are no traces of drift of any kind. On the top we join the road from Ewood Bridge. High up on the very top, away from all drift, is an apparently scored surface of rock, the grooves going S. 30° W. (magnetic). Is this only natural weathering? It is. The Moorcock Inn is passed half a mile beyond. No trace of drift is seen; not even a foreign pebble. I see another example of sandstone ribbed by weathering. On going down the other side of the moor and approaching the village of Lane Head, near Broadley Station, we once more enter a drift-covered region. Boulders of ash and felsite are the only erratics noticed. At Smallshaw is more drift, which is here heaped up in typical moraine hills. Lake District felsite of a greenish colour weathering white, is the only erratic noticed. Boulders in the moraine are often striated. We come now to Rochdale by the moor road, and return by the Edenfield Road, going by Naden. At Cheesden are heaps of morainic drift, with felsite and red granite in thick masses. The moraine here is heaped against the south-west side of the mountain. The road to Edenfield now keeps close along the edge of the drift plateau and along the base of the mountain. The drift at Edenfield is of the same character. I go to Stubbins. Clearly the drift found at the quarry there is morainic, and hills of morainic drift are seen. Bull Hill is unglaciated.]

Manchester to Middleton Junction, Castleton, Rochdale, and Todmorden

[To the south of Castleton are rolling drift hills, looking like a typical moraine. These hills bend to the south for some five miles towards Oldham. Is this the moraine at last? Rock outcrops between Rochdale and Smithy Bridge. I go to Todmorden, finding it non-glaciated. Some drift may have gone to Todmorden by way of Littleborough, accounting for a boulder found by Professor Boyd Dawkins at the new reservoir.

I return to Castleton. At a brickyard on the drift hills here is a boulder of gray hornblendic granite, 3 feet x 3 feet x 2 feet; also striated limestone, gray compact felsite, ash, red granite, sandstone, shale, fossiliferous permian (?), and hornblendic gneiss—many being finely glaciated. Limestone is here less common than the Lake District rocks. I climb up one of the knolls and find it largely made of red sand. I then walk southward, keeping on a succession of conical hills. Of these the highest and most conspicuous is Tandle Hill, crowned by a circle of trees, and of conical shape, made mainly of red sand, which is probably derived from the trias. Conical hills are all about here. The line of hills keeps west of the road from Oldham to Rochdale.

I go to the village of Stake Hill, which is in the midst of low drift hills, apparently inside of the moraine. This is on the road to Middleton over the railway. I now turn east towards Chadderton Park, and pass through a series of rounded morainic hills close to Chadderton Hall. On the new road are good exposures of sand and clay. I find flint in the sand here. On the Middleton Road is fine red sand, showing beautiful false bedding. On top of it is a tough clay full of angular stones, and below it is a gravel and loam. The sand contains many fragments of coal. The clay is not till, but is a clay with blue streaks identical with the 'Hessle clay'—tough, and comparatively free from stones. I return from Middleton Junction to Manchester, and cut through a deep and broad deposit of drift just above Newton Heath.]

Rawtenstall and Rose Grove

[From half a mile below Ewood Station to the station the railway cuts through moraine hills. The other railway to Accrington cuts through them at the same place. We keep along the edge of the moraine for one mile, seeing it banked against the mountain.

I go up Burnley Road from Rawtenstall. Morainic hills occur at Rawtenstall Cemetery. At Crawshaw Booth we ascend rapidly. 'Fringe drift' now occurs, and the region is perhaps non-glaciated. At Love Clough I go west, climbing across a high hill towards Accrington. Drift continues part way up the hill, but on top there is no drift of any kind. I found fossiliferous limestone pebbles in the valley near Love Clough. Is this a glacier from the north, stopped between there and Burnley? Far up the hillside pebbles of Lake District ash were found (non-glaciated). On descending the Accrington side of the hill, and reaching a point some 200 feet from the top, round pebbles of local sandstone occur, and an occasional pebble of Lake District felsite or ash. One of them showed traces of striæ. No striæ occur on the rock, and the whole region is apparently non-glaciated. This is 'fringe drift,' and an evidence of submergence. The waters came up to a certain level (1,000 feet?) on both sides of this hill, being about the same level as Holcombe Hill. Drift continues to Accrington, various exposures showing that it lies in a thin covering on non-glaciated rock. It consists of angular fragments of underlying rock, with a very slight admixture of round pebbles of Lake District greenish gray felsite and ash. There is no trace of the moraine.

From Accrington I go to Baxenden and Haslingden. In a quarry by the roadside is non-glaciated sandstone. Beyond Baxenden are great mounds of gravelly drift, heaped up in hills like a moraine. It is composed almost entirely of local sandstone boulders, only a few pebbles of Lake District felsite being seen. None are striated. It looks like a river wash. I see no signs of glaciers about Baxenden or Haslingden.

I now take the train for Rose Grove, Padiham, and Simonstone.

We pass through a non-glaciated area, until reaching the deep drift west of Rose Grove. I examine this, and find it to be true moraine till, a clay full of striated boulders of limestone and sandstone. Limestone breccia, fossiliferous gray limestone, and dark non-fossiliferous limestone all occur here, but no Lake District rocks. Here the deposits are the same as those east of Colne in the Moors. It seems to be the true moraine of the Wharfedale and Aire glacier.

Padiham is built upon hills of drift (?). Masses of drift containing limestone boulders are cut through just before reaching Simonstone Station. This looks like a moraine.

At the station we seem to be passing out of the moraine, rocks appearing, and the ground getting more level.

Below Great Harwood we make a cutting a mile long through apparently morainic drift, until rock appears.

Is this the moraine bounding the south side of the glacier, which came through the Pendle Hills in the cutting made by the Calder ?]

Manchester to Bolton, Chorley, and Blackburn

[The moraine hills so finely seen before reaching Clifton Junction cross the river at that point; we enter them just beyond the station, and are still in them at Dixon Fold.

These hills are largely composed of horizontally stratified sand. At Stoneclough we seem to pass out of them. Hills covered with drift occur beyond Bolton; but not at Lostock Junction—these are seen to be made of rock within, with no proof of glaciation. About Horwich Junction are low hills (of drift ?), but no characteristic moraines. Rock outcrops at Adlington. About Chorley are a number of rounded drift hills. Some of these are made of yellow sand. North of here is rock covered by drift. Deep hills made entirely of boulder clay and sand occur at Heapy. They are full of boulders. It looks like a large moraine. Red sand is on top of the till. The mountain is to the right, and the moraine makes fine hummocks heaped against its side. A good exposure is in the railway cutting. It makes ridges parallel to the railway and the side of the mountain.

We near the mountain side, seeing outcrops of unglaciated rock and getting apparently outside of the moraine at Woodside; a signal-station passed before arriving at Brinscale. Near Withnell Station we cut through a great hill of till, full of boulders. The mountain ridge is now nearly a mile to our right, and we are again in the glaciated area.

Before reaching Fenniscowles we again cut through some large hills of bouldery morainic drift, and are now on open rolling ground, with many deposits of reddish sand. All the sand deposits are red and well stratified, being made of triassic sandstone, and are the same as the deposits at Stockport. There is a high rock ridge north of Blackburn. From Blackburn I return direct to Bolton. Just above Blackburn to the south are deep exposures of sand, followed by clayey drift, full of angular sandstones, at Lower Darwen. Rock outcrops before reaching Over Darwen, as if we were in a fringe drift merely. At Over Darwen and at Spring Vale the fragments in the drift are almost entirely local; and they are mainly angular. Just above Spring Vale are non-glaciated rocks. On the south side of the tunnel above Entwhistle is some drift containing many rounded boulders of local sandstone, &c.; but the drift at Turton looks like fringe drift, and rests upon non-glaciated rock. No signs of any true moraine or of glaciation are found between Blackburn and Bolton.]

Bolton to Bacup

[There is probably a medial moraine between the ice-lobe of the Irish Sea glacier and the glacier descending from Settle and thereabouts.

Bacup is built upon mounds of till. It is a clayey till, full of scratched stones and containing pebbles of felsitic ash from the Lake District, and occasional boulders of red granite. It is a typical terminal moraine.[1] North of Bacup granite is very rare or absent, though limestone boulders abound; but south of Bacup granite becomes abundant.

It occurs in such large boulders, that they are quarried for road material at Whitworth. A granite full of red felspar occurs at Bacup; a black and white granite at Whitworth. Lake District felsitic ash is common at Bacup. This lobe of ice has clearly come along the west side of Pendle Hill, while farther north we get into a stream of local origin, full of limestone from Ribblesdale.

I walk northward on the road towards Burnley, as far as Heald, and see no trace of drift. I then go west across the watershed of the Irwell to Deane, finding no drift except fringe drift. The fringe drift consists of fragmentary and local sandstones lying in clay, clearly due to the blocking up of the River Whitewell lower down the stream.

I reach the moraine at Lumb, where it fills up the valley.]

A flint pebble has been found on Horncliffe Moor near Rawtenstall at 1,000 feet.[2] Others occur in the drift in Rossendale Valley. (Flints are also found at Blackpool, on Holcombe Hill, &c.).

Holcombe Hill and Blackburn

[From Bury I go to Holcombe Brook viâ Tottington. Rock is exposed on the banks of the Irwell, but, after crossing it an abundance of morainic till is heaped up in moraine hills, mainly made of carboniferous sandstone. This drift is well shown at Westfold. There is a fresh exposure in the new railway cutting, the typical till being full of stones and boulders. At Greenmount is a hill of till. At Holcombe Brook is drift, which increases in quantity as I climb Holcombe Hill. On top of the hill, on the moor 600 feet above the railway station, is a great deal of drift. Boulders cover all the top of the mountain as if it were a moraine. Boulders of sandstone and of Lake District felsite are most abundant. The tower on the mountain (which can be seen from Ramsbottom) is on the drift covered moor (the moraine ?). Drift is abundant also on the west side of the .mountain; but on rising 50 feet and going north-east the drift suddenly disappears, and we enter upon rock with no trace of drift whatever. Notwithstanding the quantity of drift on this hill and its altitude above the sea, no moraine hills are to be seen. Can this possibly be the shoreline of an extra-morainic lake ? No; it is a true moraine. The drift makes a terrace on the west side of the mountain. It is the moraine of the Irish Sea glacier.

---

[1] I thought this at first sight to be the moraine, but it is really outside the moraine, and is *fringe drift.*

[2] *Trans. Manchester Geol. Soc.*, 1872-3, p. 41.

I now go north-east and descend to the Irwell at Stubbins. On descending 200 feet drift occurs, being apparently fringe drift. A fine exposure is at Stubbins Vale in a quarry, where 20 feet of drift overlies the sandstone. The drift is a loose yellow mass, closely resembling glacial till. It is full of rounded pebbles, boulders of sandstone, Lake District rocks, and occasional red granites, and some are striated. Stratification on a large scale, only, is seen. Clay occurs in the deposit. It is a moraine till, made by a glacier.

Stubbins Station is 100 feet lower than Holcombe Brook Station.

I go by train to Ramsbottom, then northward to Accrington, and thence to Blackburn. Between Ramsbottom and Stubbins is no trace of glaciation. No striæ were ever observed in this region. Was the glacial dam across the Irwell at Bury ? Above Stubbins is a large mass of drift. Just west of Helm Shore is a high (non-glaciated ?) red granite block. North of here I see no certain signs of glaciation until reaching a point half a mile north of Haslingden, where we cut through a fine moraine (?). There is a deep cutting in the till filled with boulders. There are also high hills of drift. The moraine here is a watershed.

Baxenden is *inside* the moraine, which forms an amphitheatre around it. Deep drift is heaped up on the hills, and many large boulders are seen south-east of Accrington.

I go west from Accrington. We cut through deep drift just before reaching Rishton. Drift is also plentiful at Blackburn. I go to Manchester viâ Bolton. We seem to be in the glaciated area.]

Entwhistle to Whalley

[I take the train for Entwhistle. At Turton are great hills of apparently morainic drift.

About Entwhistle are more such hills. At the station a hill is opened showing it to be made of coarse gravelly drift, full of boulders of sandstone, conglomerate, Lake District felsite, red granite, slate, and a boulder of serpentine.

I notice no limestone here. I go northward finding morainic hills here and about the reservoir. Is this the north side of the glacier which came to Rochdale and Bacup, and crossed Holcombe Hill, which is in sight from here. There is a low pass to the west through which the glacier could readily have come.

Boulders often glaciated continue high upon the hill, but in getting near the top they suddenly disappear. Thus at Cranberry Moss (Bull Hill Fire Clay Works) there is no trace of drift. I go to the valley of Bull Hill, and thence to Darwen and Blackburn on the Bolton Road. Lake District erratics and sandstone boulders occur before reaching Sand Hill, also clay and sand. At Sand Hill (west of Spring Vale Station) is a hill of red sand, identical with the sand near Oldham. It contains fragments of coal, and is red above, with finer, lighter sand often below, and is false bedded and compact so as to resemble a decomposed sandstone (?). It is the same sand as that at Stockport. What does it mean? Great morainic hills of drift occur at the boundary of Blackburn Borough, and the valley is filled up with thick deposits of red sand and gravel.

I take the train from Blackburn to Whalley. Blackburn seems to be built upon a hill of drift. High hills of drift are about Blackburn Cemetery; and just before arriving at Wilpshire are deep cuttings through morainic hills. Rounded hills of clayey till are here, but at the station rock appears, and a tunnel through the rock follows. We emerge in an open drift-covered valley.

At Whalley I go up the Calder into the gap through the hills.

Here are morainic hills in great number, being southeast of Whalley. Drift covers Clerk Hill.

The moraine of the felsite-bearing glacier probably crosses Longridge near the town of that name.]

Molyneux to Burnley

[I go to Bury viâ Clifton Junction and Molyneux. One mile east of the railway is a fine exhibition of the moraine —which should be photographed from the railway—from a point half a mile south of Clifton Junction.

Typical moraine hills are finely exhibited. The moraine is at Heaton Park or thereabouts. At Molyneux Station we cut through and enter these hills. They are very sandy and lie east of Molyneux Station; a typical moraine. Is this the *back* of the moraine? North of here the hills extend on the west side of the Irwell as well as on the east side; the Irwell here cutting into the back edge of the moraine. The railway ascends and cuts more deeply into the moraine between Molyneux and Ringley Road. At Radcliffe we are quite away from all signs of a moraine. Just north of the station sandstone is exposed, with drift on the top. Level ground occurs, but hills are seen one mile to the east.

From Bury to Summerseat there is no sign of glaciation, although a quantity of drift (fringe drift ?) is seen. There are no glaciated rock surfaces. A thin covering of drift lies upon the rock, which has the appearance of rock in an unglaciated region. More hills of drift are cut through before we reach Helm Shore. A quarter of a mile north of Haslingden is the terminal moraine of a glacial tongue which came southward down the valley. The highest point of the railway is where it cuts through this local moraine. A non-glaciated ridge occurs to the east.

A glacial tongue seems to have extended to near Haslingden. We again cut through typical morainic hills filled with large glacial boulders just south of Accrington.

The moraine here makes a fine ridge of boulder clay, having typical morainic contours. Boulders project in the railway cutting and are glaciated.

Beyond Accrington is shale covered by deep drift in which are large boulders, the region being clearly glaciated (moraine ?) From the shape of the hills, I judge the glacier to have come from the north-west.

At Huncoat rock comes to the surface, and I see no signs of glaciation. So, too, from here to Hapton. At Hapton Station, the rock is well exposed, and is non-glaciated, and has no drift upon it. A high knob, Pendle Hill, lies due north of here, and has warded off the glacier. But between here and Rose Grove we once more cut through a fine and typical moraine, full of boulders. This is the moraine of a glacial tongue which came down on the east side of Pendle Hill. The railway cuts through the moraine just west of Rose Grove Station (Map VII., p. 188).

From Burnley I walk eastward through Worsthorn, and thence due east up to the top of the Moors. I find an entire absence of glaciation. At 600 feet above Burnley is a local drift, consisting of clay in which are rounded boulders of sandstone, some of them showing faint striæ. The head of a small stream is just below this point, and this is a local wash. There are good examples of the scratching of sandstone pebbles not done by a glacier.

I walk back to Worsthorn and thence northward to Nelson. On approaching within a mile of Nelson drift filled with local pebbles and boulders appears in great quantity, being 200 feet above the railway station. At Nelson there is deep drift made of a clay resembling that of Bacup, and containing boulders of sandstone and limestone. The moraine is probably between Nelson and Haggate. Between Nelson and Brierfield there is also deep drift, resting upon rock.]

Colne

[I go by train to Colne. Having passed through the great hills of drift between Molyneux and Ringley Road, I see rock at Radcliffe for the first time, and we are possibly outside of the moraine. Non-glaciated rocks occur about Bury and north of there. Just above Stubbins is a great mass of drift resting on non-glaciated rock. The drift gets much thinner as we go up stream from here, and seems to be almost absent about Helm Shore. As to the drift south of Baxenden, I am not sure as to its being a moraine, and it is possibly only drift lying upon rock. This is 200 feet higher than the mass of drift about Stubbins. Above here are rock surfaces that are unglaciated. Immediately south of Accrington is a deep cutting through drift, in which I see numerous large projecting boulders of sandstone. This looks like a section through a moraine. More sandstone boulders appear east of Accrington, but here they are seen to be in a drift resting upon shale. Non-glaciated rocks also occur to the eastward, and I see rock under the drift at Rose Grove which does not seem to be a moraine.

In fact I do not think the glacier came as far south as Burnley. There is deep drift at Burnley Barracks. Just below Brierfield Station is a mass of drift containing limestone pebbles, but north of the station rock is seen under the drift.

From Colne I drive north-east to Laneshaw Bridge and to the moors, on the boundary line between Yorkshire and Lancashire. At the Yorkshire tongue into Lancashire is a sandstone quarry exposing 25 feet of drift on top of the rock. The drift consists of horizontally stratified sand overlaid by till. The till is a clay full of glaciated fragments of limestone and sandstone. The limestone erratics are of all sizes and are well glaciated and scratched. I can find no striæ on the sandstone here. On the road the sandstone is exposed with no drift on it or sign of glaciation.

The limestone drift abounds south-east of this locality, and old kilns are here where it was used for lime. The drift is banked against the north-west side of the Boulsworth Hills, yet it seems to be more or less confined to the valley of the Laneshaw stream, and it has no distinct moraine contours. Is it only a fringe drift? Has the moraine here been obliterated? We pass the watershed before reaching Ickornshaw. Has the ice come from the east or from the west? I drive to Foulridge, but find no striæ and am not certain as to glaciation. Rock is exposed also at Colne, but shows no signs of ice action.]

Stockport

[I get out at Heaton—Mersey Station (Midland Railway). In a large brick pit here is an interesting section at an elevation of 160 feet. Fine sand 4 feet.

Laminated clay with *Turritella*, *Breccinum*, *Littorinea litorea*, and occasional boulders, 36 feet.

Yellow (sea) sand and gravel (with shells) 2 feet.

Tough till, reddish gray clay containing a few striated erratics, but clearly aqueous, 25 feet.

The lowest deposit here, the till, is without shells, and is also very free from stones. The boulders it contains are Criffel granite, Eskdale granite, andesite, diorite, felsite, carboniferous limestone, and grits; which are often finely striated.

The band of sand and gravel which separates this so-called lower till from the laminated clay is sometimes only a few inches in thickness. This separating sand is clearly marine, and is full of marine shells.

The 36 feet of laminated clay has streaks of sand and gravel, and shows fine ripple marks. Some of this clay is not laminated. It is nearly free from stones. It contains occasional boulders of andesite from the Lake District. These are at its bottom probably washed out of the underlying boulder clay, and do not indicate ice during the formation of the laminated clay. The upper part shows alternations with sand and the beautiful lamination, ripple marks, and shells never occur in this part. The clay is often contorted. The ordinary brick-clays break perpendicularly into cracks and cubic fragments, but this laminated clay never breaks in this way.

The fine sand on the top of the laminated clay is bleached by a great bog included in it. The peat bed extends 100 feet. Sand is on the top.

These deposits on the top of the till are probably *post-glacial.* The beds here are important as being the *highest* post-glacial deposits I have observed, and showing a probable *post-glacial elevation of* 160 *feet.* This helps to reduce the amount of inter-glacial submergence.

I go to the River Mersey at the new viaduct, Stockport, where resting on red triassic sandstone is coarse river gravel, covered by iron rust. The glacial drifts have all been washed out of this valley, which has been cleared out in post-glacial times, although the old river valley at a higher level can be traced through Stockport.

At Brunnington, near Great Portland Street, Stockport, cliffs of deep red permian sandstone are exposed which are quarried for sand.

Over the sandstone is:—

(1) A red till, made of the underlying rock, being red and sandy and with foreign blocks. This gradually passes into a coarse gravel in another part of the cutting. Is this glacial?

(2) Loess or silt. A white or light-gray material, as light as loess; this in part alternates with thin seams of clay, and shows ripple marks, suggesting that it represents the upper part of the laminated marine clay seen at Heaton Mersey.

(3) A great thickness of tough gray clay. A boulder of loess lies in it, at the bottom.

(4) A gravelly wash with boulders.

I go to Denton where are fresh cuttings through a mass of tough, dark-gray till, weathering in the upper part into columns or cuboidal fragments, the joints being bluish, like the Hessle and chalky clays. It contains irregular fragments, but is comparatively pure in the lower part. The elevation is over 200 feet. It is an aqueous deposit. Lines of sand sometimes occur in it; and if the sand is well marked we have an upper and a lower boulder clay, according to Hull. There is no distinction whatever between the upper and the lower boulder clay. Sand may vary into either.

The clay here is, perhaps, 50 feet deep. Generally there is a little sand below it, and between the clay and the rock. This is not the case at Liverpool, where the clay rests directly upon the striated rock. The rock is never striated here. The clay is identical with the great chalky boulder clay, Hessle clay, &c.; and was made in water, which perhaps washed the ice-foot.]

New Mills and Hayfield

[I go to New Mills. East of Stockport to Hazel Grove there is flat ground; while farther on are hills made of rock, well seen in the railway cutting; east of this there is drift overlying the rock; rock also appears about Disley. At New Mills rock is exposed with no sign of glaciation. I go to the town and find in the valley a deposit of brick-clay, well exposed in a brickyard below St. George's Church.

This clay resembles the Hessle clay and cracks into columnar pieces as it stands. It is full of water-worn, angular, and striated stones, both local and erratic. Many of these are beautifully glaciated, being covered with very well-preserved striæ. It is like the deposit at Strines. The stones are better glaciated than in the glaciated area. Among the erratics are numerous boulders of red Scotch granite, Lake District felsite, also hornblendic andesite, and an interesting picrite full of sharp crystals of diallage, often in twins.

Above the church is a quarry of sandstone (Brumbrae Quarry). On top of this sandstone (carboniferous) is a deposit of stony clay much resembling till. The deposit is about 3 feet deep and is a yellow stony clay, full of angular fragments of the underlying rock, but containing in addition some foreign pebbles of granite, felsite, &c. The underlying rock is not planed off, but is much broken at the top, and merges into the clayey deposit gradually. Just as the solid rock merges into broken rock, so the broken rock merges into a clay filled with angular rock fragments, and so also the clay becomes purer above.

The upper part of the clay contains pebbles and sandy streaks. Sections about Birmingham and in Central England often show these features, which are quite different from the glaciated floors farther north and west.

(Compare with the till on the glaciated carboniferous sandstone near Newcastle.)

The whole deposit is thinner, more stony, and more made of the underlying rock than that at the brickyard at a lower level. Thus it agrees with similar drift deposits on the east side of the Pennine Chain, which gradually thin out, and become stony as we go into the mountains and up to the higher ground.

A lake extended up the two valleys which branch at New Mills.

I take the train to Hayfield. Soon after passing out of New Mills we cut through a thick moraine-like deposit full of boulders. Beyond here, and at Hayfield, rocks come to the surface with no drift, and are apparently unglaciated. I return to the drift hills, which are cut through at New

Mills Tunnel End signal station, and find them made of sand and clay in stratified, nearly horizontal, beds.

It is a deposit 50 feet or more in thickness, and consists of coarse, yellow sand, horizontally stratified, overlaid by a deposit of clay containing boulders. The sand is made of carboniferous sandstone, and appears to be a local river deposit. It is clearly the same deposit which I saw in the brickyard above.]

Strines to Chinley

[I go to Strines and examine the railway cutting west of the station. The cutting is through a thick mass of dense clay, filled with glaciated boulders; a true boulder clay. Among the boulders are numerous fine grained felsites; also coarse granites. A ridge of this boulder clay extends across the valley like a great dam between Strines and New Mills, as is well seen by looking down upon it from above.

I climb up a hill to the north, finding boulders of felsite abundant, sometimes 2 feet long and glaciated. I go to the top of the hill 400 feet above the railway, still finding boulders.

I then descend to New Mills, where are many erratics of Lake felsite. I go to Low Leighton, where the boulder clay is abundant. I pass St. James' Church and the quarry, which is clearly covered by till, the rock underneath being more or less planed down.

I go to Beard Hall, which is on top of the hill, and here, close to some outbuildings at the back of the house, is a fine erratic of syenite, measuring 3 feet × 3 feet × 2 feet, and partly buried. The fields here are full of boulders of felsite and granite in addition to local blocks.

The boulders from Strines, New Mills, and this locality I class together.

I now turn eastward, and at the farm, Brown Hill, Ollersett, find a large collection of erratics; granites and Lake District felsites, with quartzites and sandstones, are the principal varieties. I go still farther east, and find similar ones at the cross roads, where striated stones occur, resting upon non-glaciated rock. Beyond here in an old lane, leading up the mountain, is a great quantity of erratics of granite. This is like a moraine in the abundance of its boulders, but it has not the characteristic features of a moraine. We now suddenly rise into driftless regions. Not a pebble or an erratic is to be seen. I walk to Chinley, not meeting with drift until near the station. The elevation of the edge of the drift here is at least 600 feet above the station.

I go to Manchester (Midland Railway). West of Romiley is a hill of carboniferous shale *not covered by drift*, and apparently non-glaciated. I begin to suspect that the moraine is near Manchester, and that the drift farther east is fringe drift. Does the moraine of the Irish Sea glacier extend from Stockport to Cheetham Hill (Manchester); to Bury; to Ribchester; to Bleasdale Moors; to Black Combe ?]

Macclesfield district

[At Macclesfield I drive eastward up the mountain. I first stop at the park to see the great boulder. It is finely glaciated. Its original home is Cumberland according to the description on it. I find some fragments of marine shells in the sandy gravel from a grave in the cemetery. This is the place celebrated for its marine shells. The gravedigger tells me he often finds them; never in clay, but in sand, particularly at a considerable depth. The cemetery is all drift, mostly aqueous sandy drift. At a brickyard beyond the railway station is 30 feet of fine pure brick-clay, overlaid by 5 feet of impure gravelly stuff, the gravel holding much granite. Boulders of granite and greenstone abound about the town. I go up the mountain to the east of Macclesfield Forest. Boulders are plentiful part way up the mountain. Their main upper limit is at Eddisbury Hall, about 400 feet (?) above the town.

Above here the carboniferous sandstones outcrop, and no drift is seen, but there are a few scattered erratics.

There are some erratics at Walker Barn and near Setter Dog Inn. Could these have been carted here from a lower point?

No striæ are visible on the rock exposures here, and no sections of till are anywhere to be seen; yet the region may be glaciated, the top of the ice having reached this point, about 1,200 feet above the sea.]

There is an excellent paper by C. Darwin, 'On the Transportation of Erratic Boulders from a Lower to a Higher Level,' *Quart. Jour. Geol. Soc.*, 1848, v. p. 315.

He thinks that coast-ice has done it. But while pack-ice, as shown by Arctic voyagers, can raise stones 20 or 30 feet, it cannot raise them 1,000 feet. I am beginning to believe in floating icebergs from a land glacier, in order to explain certain things, such as the marine till at Montreal and in South Lancashire.

Vide paper by Prof. T. McKenny Hughes, 'On some Perched Blocks and Associated Phenomena,' *Quart. Jour. Geol. Soc.*, 1886. (He describes erratics on limestone pedestals, which latter are striated on top. These are in the Lake District and at Norber, &c.) Also:

'On Transport of Erratics to Points higher than their Source,' Helmersen, *Die Wanderblöcke Russlands*, p. 68.

Also my Report Z., p. 222.

From Macclesfield we drive to Setter Dog Inn, and Walker Barn (Vale Royal), high up on the mountain.

No trace of glaciation is found on the rocks. Not a fringe of boulders is seen wherever a lateral valley opens out from the east. Walker Barn is in a valley opening out from the east. It is at the head of the valley in a sort of bay, surrounded by higher hills. Here, resting on top of the decomposed sandstone, is a thin deposit of sandy drift, mainly local, but containing, especially at the top, a number of rounded erratics of granite, felsite, &c. I find also a shell fragment in it. There is no sea-sand here, the sand-drift being made of the underlying, decomposed sandstone. The drift thins, and on ascending becomes thinner, only a foot thick, until it completely disappears. It is a temporary aqueous deposit. It thins out just like the drift on the east side of the Pennine Chain, becoming sandier, more local, and thinner as it approaches its edge. On the other hand a glacier-made deposit is thicker, and more massive at its edge, and ends suddenly. Besides, there are no striated rock surfaces here, the whole aspect being identical with that of a non-glaciated district. Nor is there any sign of marine submergence. No beach-line, no sea-sand, no rolled local shingle. Moreover, the shells are not littoral shells, but are just like those now at the bottom of the Irish Sea, and are the same as shells now found in the till of the Cheshire plain. The boulders found here are also the same as those found on the Cheshire plain, and so are the flints.

Neither an ice-sheet nor a marine submergence brought the shells here.

The moraine of the Irish Sea glacier is at the foot of this lateral valley. Ice blocked up the outlet of the valley, and made a temporary extra-morainic lake, and this valley was filled with water just as lateral valleys emptying into the Rhone Valley were converted into temporary lakes. Thus we get this thin deposit of drift, into which both boulders and shells were carried by icebergs breaking off from the glacier. It is an excellent example of an extra-morainic lake.

I return to Macclesfield, and go to a hill south of the town, above St. James' Church. Large boulders of granite are common here, but the hill is made of shale, and the moraine proper is probably farther east.

Between Macclesfield and Bollington we cut continuously through deep drift, and moraine hills composed entirely of drift occur at Bollington, and are exposed at the station.

The moraine is well shown just beyond Bollington. Then the railway follows the inside edge of the moraine, and often cuts into the hills. There is a deep cutting in the moraine hills at Poynton Station which is on the inner edge of the moraine. The moraine here does not form conical hummocks, but makes low rounded hills. Farther north it is still flatter, making merely a rolling country between the mountains and the plain.]

(The drift between Marple, Hyde, and Manchester has been already described.)

Buxton (Derbyshire) and Taxall

[At Buxton we walk to the limestone quarries, finding no trace of drift. No drift or striæ are on the limestone. We walk westward to Goyt's Moss at the head waters of the Goyt river, seeing no drift whatever. We now turn down the picturesque ravine of the Goyt River, free from all drift; and then westward to Saltersford Hall and Jenkin Chapel, having crossed a high ridge and descended into the Saltersford Valley. Here first, in the valley north of Jenkin Chapel, does drift occur in the form of gravel, and numerous boulders of Eskdale granite, Lake felsite, and felsitic ash, &c., often nearly 3 feet long.

We then go northward down the valley to Taxall and Whaley Bridge, finding erratics abundant about Taxall. The glacier probably ended about Taxall.]

Great Crosby

[At Moorhey brickfield, Great Crosby, is an interesting section through a boulder clay which shows distinct lines of stratification, and is full of erratic scratched stones with very occasional shell fragments.

This clay is washed, and an artificial gravel is made from it which is very similar to many glacial gravels, and is most instructive. It contains both rolled and glaciated pebbles, and many shell fragments of turritella, cardium, astarte, cyprina, &c.

Among the erratics are numerous carboniferous limestones, with granites and Lake felsites. There are more and better striated erratics here than in a moraine.

The boulder clay is eroded into hollows on the surface by atmospheric waters, and is decomposed into sand. The process begins in a point. The clay cracks in drying; water percolates through the cracks, and washes away and decomposes the clay, leaving a white sand with some sticky red clay; and then hollows begin to form.

Underneath the upper red boulder clay, with its striated erratics and abundance of shell fragments, is a *true till,* reddish gray, containing occasional Lake erratics and shell fragments, with large angular pieces of Keuper sandstone. It is 2 feet thick. Some great cakes of Keuper are 6 feet long and glaciated, both on top and bottom. It is an admirable example of a striated pavement. The striæ indicate glaciation from the north-west. This true till is a genuine ground moraine; the (upper) boulder clay having been made during the retreat of the ice. Beneath the reddish gray till is a gray, kneaded, and pressed 'marl' or shale, washed and broken up. The sandstone blocks are frequently pressed into and imbedded in the broken and distorted shales. These latter are often the only represen-

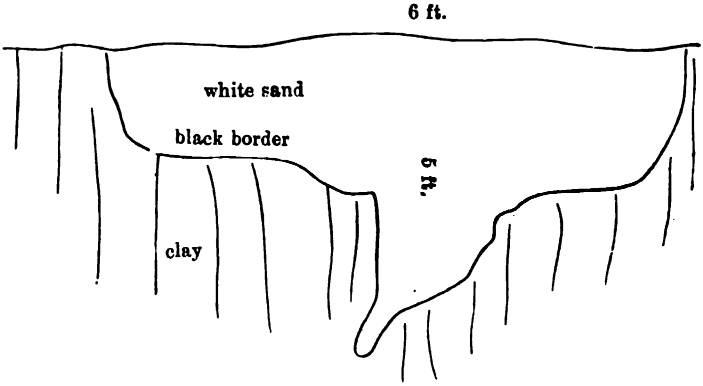
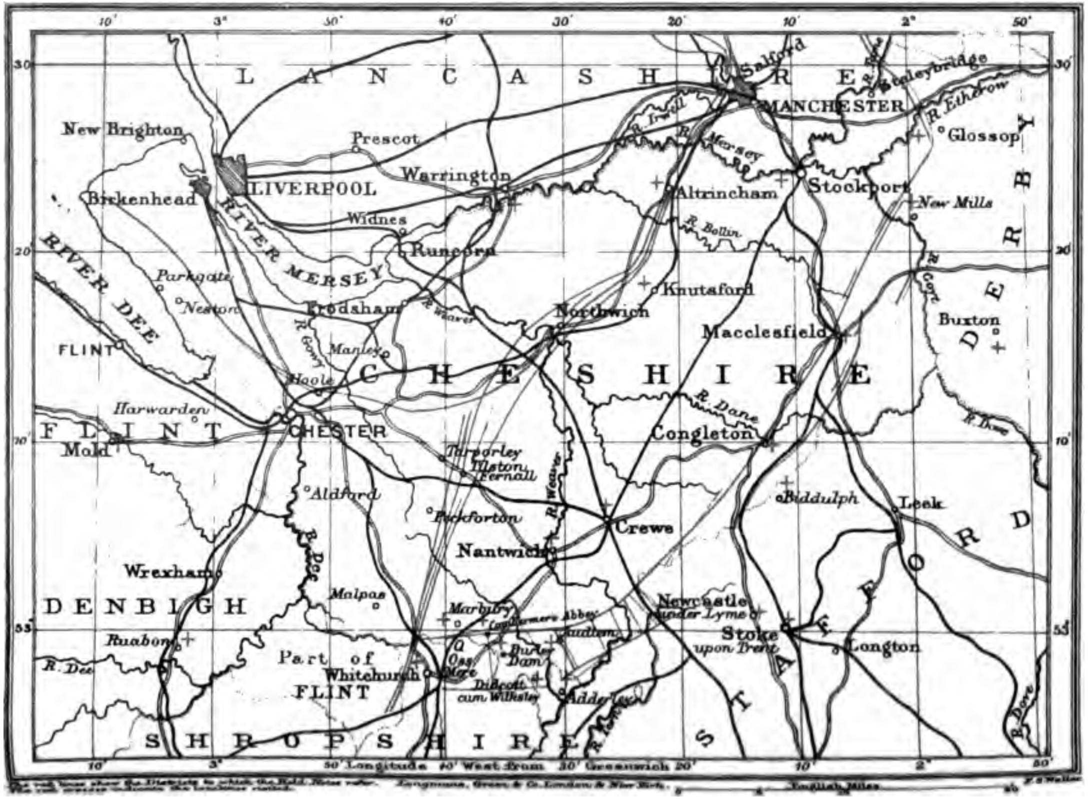


FIG. 35.—Section of Clay, Moorhey Brickfield, Great Crosby.

IX. SOUTH LANCASHIRE AND CHESHIRE.



tatives of the ground moraine, and are directly overlaid by the red boulder clay—the true till with foreign stones and shell fragments was seen only in one place.

This section has been described by Mr. T. Mellard-Reade (*Quart. Jour. Geol. Soc.*, 1885, p. 454), but in his description there is no notice of the till proper. The crushed and broken-up marl has the striated pavement pressed into it. It is not till.

The important point of my discovery is that here, perhaps for the first time in Lancashire, has been found a true till, made mainly of the underlying rock, but also with Lake pebbles, and with shells carried by the ice out of the sea. The boulder clay full of scratched erratics lies unconformably on top of the till.]

Adderley to Whitchurch

[From Manchester to Audlem is a great level plain, almost perfectly flat, rising some 40 feet about Stockport, and sinking 30 feet below Manchester at Nantwich, south of which the plain again rises. On approaching Audlem, a well-marked terrace and some mounds appear, and, in the railway cuttings, these are seen to be made of red sand. Between Audlem and Adderley is a great collection of hummocks, small meres and moraine ridges. I get out at Adderley, and in the Adderley estate find a large collection of erratics, mostly Scotch, mixed with Lake felsites, carboniferous and silurian limestones, &c. Many of these are finely glaciated. The granite boulders are also well striated.

I walk north-west across the country, finding the moraine sandy, wide, and forming low rolling hills, very different from the moraine on the high ground. There is a preponderance of Scotch boulders as compared with the edge of the ice at Mosley and New Mills. The moraine here was made under water—the elevation is about 300 feet. Various large boulders, sometimes glaciated, one of them over 4 feet long, lie at the bend of the lane east of Dodcott-cum-Wilksley.

At Dodcott-cum-Wilksley is a sand-pit, showing 20 feet of grayish-yellow sand overlaid by 2 feet of boulder clay.

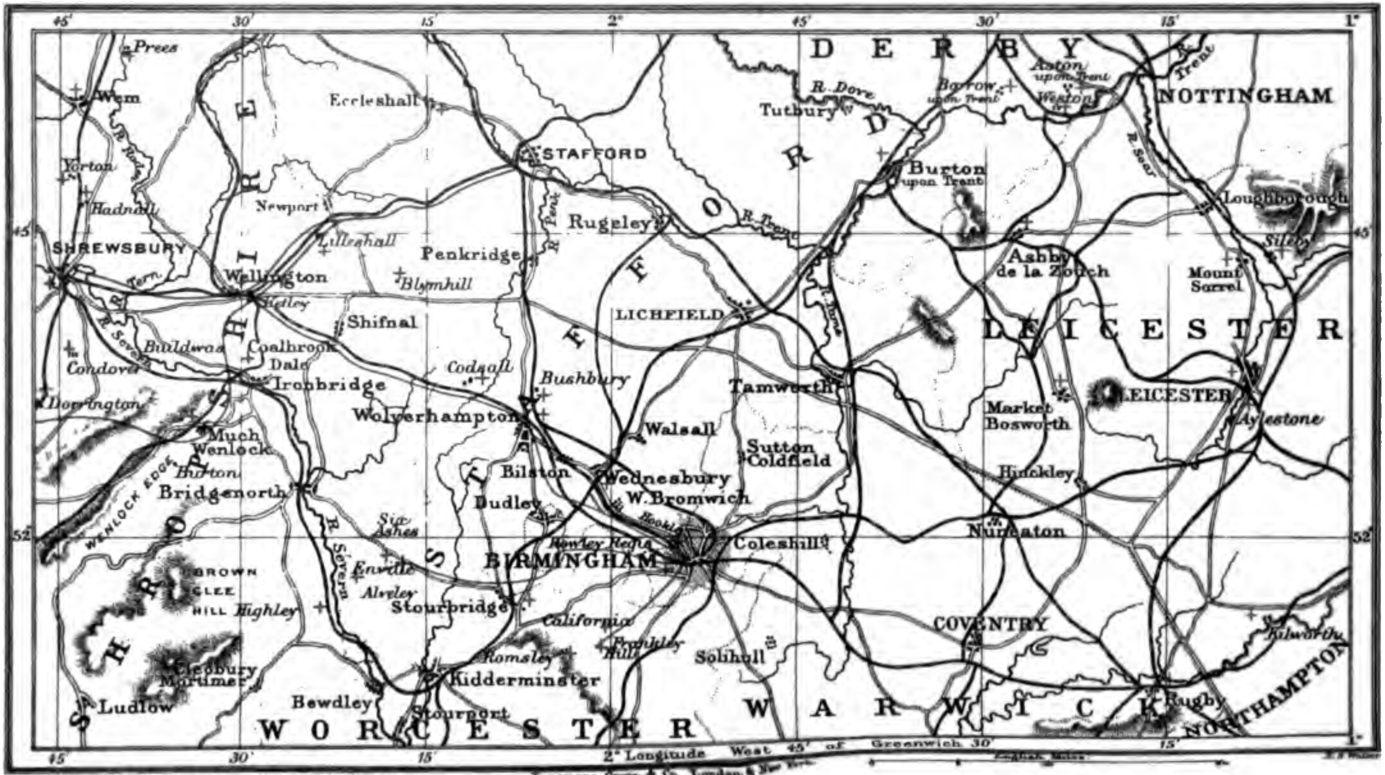
The sand is full of green particles of felsite, red grains from the trias, bits of green shale, and minute fragments of shells, having come from the north. But by the false bedding, the current which deposited it is shown to have come from the south, i.e. from higher ground.

It looks like a drift deposit. An irregular band of dark clay occurs in it. Several large glaciated boulders of felsite (Arenig ?) lie by the roadside in the village. There is gravel about here in the fields. I go to Burley Dam, and thence to Combermere Abbey. In the Abbey Park, which is entirely on drift hills, is a large mere. Combermere is enclosed. Large boulders of felsite and Criffel granite are common. One magnificent boulder of Scotch hornblendic granite, measuring 6 feet x 3 feet x 3 feet, well polished, lies near the mere on the south side of it at the roadside, 400 feet above sea. It is said to be the boundary of Cheshire and Shropshire. Very beautiful hummocks are seen at the edge of Combermere estate, south-west of the Abbey, in Shropshire. More large boulders of Criffel granite occur here—indeed, the greater part of the large boulders are of Criffel granite, and are well smoothed and striated.

Clay, gravel, and till are also observed. I now go towards Whitchurch: to the south-west limestone boulders become more numerous. At Broughall Chapel is a hill, a moraine ridge, and here limestone boulders abound. The limestone is all carboniferous, often fossiliferous, and possibly comes from North Wales. The elevation is about 550 feet. I descend to Whitchurch, which seems to lie just at the south edge of the moraine.

North of Whitchurch the railway ascends, and afterwards descends 250 feet to Nantwich.]

X. ENVIRONS OF BIRMINGHAM.



The red lines show the Districts to which the Field Notes refer
The red crosses indicate the localities visited.

6. *SOUTH LANCASHIRE, CHESHIRE, AND MIDLAND DISTRICT*

Whitchurch, Ellesmere, and Oswestry

[From Shrewsbury I went to Whitchurch, viâ Wem.

South of Hadnall are sections, apparently through drift, which here forms (or caps) a flat ridge. There are no hummocks to be seen, and the drift is probably only superficial and due to icebergs. At Yorton, the next station beyond, rock is exposed by the railway cutting with no drift on top of it. (Why do we always see rock just before getting to the moraine?) The rock is a light soft sandstone of triassic age. It is flat at Wem, with a plain covered with gravel; probably ditto at Prees, although here a ridge is observed half a mile to the east.

Between Prees and Whitchurch drift with boulders occurs as flat hills, which become more undulating about Whitchurch. This is probably the moraine, though it is not so distinct as elsewhere. Many meres occur north-east of Whitchurch (Combermere, Marbury Mere, Oss Mere, Blake Mere, Brown Moss, &c.), and there is 96 feet of red sand in the town.

To the east, according to the map, is 99 feet of sand in one place, and 100 feet of blue clay and sand at another.

The moraine would probably pass just south of Whitchurch.

I go to Ellesmere. We cut through a succession of lenticular hills of till, between Whitchurch and Fenn's Bank, fresh sections of clayey till full of boulders being fortunately exposed by slips in the cuts. At Fenn's Bank we have passed to the north of the moraine, where is a large bog with brick-clay and peat. This is Whixall Moss, from which peat is dug. It is clearly an old lake, and is about three miles long by two wide, enclosed in clayey drift.

At Bettisfield are more hills of drift and more bogs.

Between Welshampton and Ellesmere are fine hummocks and large billowy hills of till, often well exposed in fresh cuttings, showing the till to contain many boulders of *limestone*. This is a magnificent moraine, as fine as anything I have seen in Pennsylvania.

It is indeed a typical exhibition of the moraine with high hummocks, and many meres, all in confusion.

I get out at Ellesmere, where is a large and beautiful mere. Many boulders occur.

Four large ones are seen at the corner of Watergate and Church Streets in the town, one of which is of granite.

South of the mere the moraine knobs and hummocks are finely and typically developed, and full of boulders of feldspathic ash, carboniferous limestone, sandstone, granite, &c. Sections show them to be made in great part of unstratified till containing many glaciated stones, with which are sandy portions also.

Among the larger boulders carboniferous limestone probably predominates.

Most of the meres have neither inlet nor outlet, and lie at various levels in true kettle-holes.

Granite boulders are not common, not nearly so abundant as they are about Wolverhampton.[1]

Some of the kettle-holes are dry, some are bogs, others are lakes.

The moraine hills continue for several miles south of Ellesmere.

Cross Mere is three and a half miles south of Ellesmere.

The moraine runs approximately from the north-east to the south-west (?), corner of the Geological Survey Map, No. lxxiii.

The 'Bowling Green' is a remarkable conical hill of sand, higher than any of the other hummocks, which has been levelled off on top and laid out as a beautiful circular bowling green, surrounded by flowers and a hedge, and commanding a view of four counties.

---

[1] It is clear that at Ellesmere *two* glaciers met, one from the north and the other from the west-north-west. That from the north carrying granite was met and became confluent with a Welsh glacier, producing here an unusually large moraine. It is a medial moraine, comparing well with the Wisconsin 'Kettle Moraine.'

From Ellesmere I go to Oswestry, and thence, viâ Welshpool and Machynlleth, to Barmouth, Wales.

Beyond Ellesmere moraine hills are seen to the south of the railway. At Frankton we enter them again. They are here made of red sand, as is shown in an opening near the station. Such is often the case with the back edge of a moraine.

Just beyond this point we pass through and out of the moraine, but we enter it again shortly before arriving at Whittington, though at Whittington Station there are no hills; and we now seem to have passed through the moraine and into the non-glaciated area (?).

No drift hills are observed beyond here. Openings for rock are seen on the hillsides about Llyn-lys, and on the railway farther on, near Pont, are good exposures and several large quarries of limestone (carboniferous), with no covering of drift.[1]

That the moraine passes north of Oswestry is indicated by the words 'great depth of gravel,' on Map lxxiv., south-east, at a point two and a half miles north of Oswestry.

The moraine then evidently passes Frondey, four miles west of Wrexham, as so well described by D. Mackintosh (*Quart. Jour. Geol. Soc.*, 1881, p. 359).

It also passes Minero, and the Ellesmere district is the most southern point of the moraine.]

Shrewsbury, Wellington, and Much Wenlock

[From seeing the meres on the Ordnance map, I am inclined to believe that the terminal moraine is farther south than Ellesmere, and runs from Ellesmere to Baschurch, to Shrewsbury, to north-west of Much Wenlock, to Buildwas, to Shifnal, to Aston, to east of Newport, to Cheswardine, and east of Market Drayton to Madeley. Lakes and drift occur at these places. The moraine makes a watershed east of Newport, &c., and granite boulders occur.

---

[1] Mr. Morton tells me that striæ going north 40° east occur on limestone cliffs north of Llanymynech, at Friesland Hill.

Going from Shrewsbury to Wellington we pass through deep cuttings in gravelly drift, but it is not hummocky. Then a great plain follows, as if a marginal lake had succeeded the glacier and levelled the country.

There is hummocky ground and some deep cuttings through till just before we reach Wellington. I go to Much Wenlock and Craven Arms by the Great Western Railway. There are deep cuttings through the till at Wellington.

The glacier probably did not get over the Wrekin. Beyond here I notice no drift, and am not sure as to whether there is glaciation or not. About Coalbrookdale are deep cuttings and huge masses of yellow clayey material, containing sharp fragments of sandstone, but I think this is a decomposed carboniferous shale. It is high hilly ground. (See *Memoirs of Geological Survey.*) At Buildwas Junction there is an immense amount of red sand, filling up the valley of the Severn, which has terraced it. The glacier must be near at hand. We go up the Severn, and now see morainic mounds of coarse gravel at the entrance to the tributary valley up which the railway goes.

In ascending this valley, however, we soon (in half a mile) get into rock and into a driftless area. We then just touched the moraine at Buildwas.

I see no drift at Much Wenlock, which is on high ground, nor any beyond here. It is known, however, to run a few miles farther west, and to be full of Scotch granite at Burton, three and a half miles west of Much Wenlock (*Quart. Journ. Geol. Soc.*). The drift about Church Stretton is in the valley, and is the fringe or marginal lake extending from the moraine north of Leebotwood to Church Stretton. South of the latter place is a sand-bank, marking the edge of the lake. This is what I saw from Caer-Caradoc.]

Shrewsbury

[From Shrewsbury,[1] where there are great hummocks of coarse gravel, I go to Minsterley, keeping all the time in a well-glaciated region. There are roches moutonnées at Pontesbury, the hills being rounded off. At Minsterley I see boulders of red granite,[2] felsite, &c., with quantities of shale and gray sandstone.

East of Hanwood Station, near the crossing of an old railway, is a hill composed of drift, being the largest deposit cut through on this line. I examine this, and find in it apparently two sets of deposits. The lower one, a red stiff till, now obscured by slips, contains erratics from the north, including Eskdale and Criffel granite, carboniferous limestone, and Arenig felsite. The upper deposit, 50 feet thick, consists of coarse gravel and yellow boulder clay, and contains purely local erratics, mainly large argillaceous shales, diabases, diabase porphyrites, &c., &c.

Striæ are very scarce in this upper deposit of gravel and boulder clay, which is in great part aqueous, and the product of glaciers coming to the south-east from the Berwyn Hills.

I find also a boulder of fossiliferous rock. This may be Upper Llandovery, having come from the south-west.

About Upper Pulley are many large erratics of white and red granite, and more abundantly felsite. These are often nearly a yard long, and the felsites are sometimes finely striated. Are these Lake District felsites? A large rounded and glaciated boulder of coarse white Criffel granite lies at the cross roads at Bagstow Hill 2½ feet × 2 feet × 2 feet.

About one mile north of Dorrington is a conspicuous and sharp kame-like ridge made of drift gravel, stratified like kame gravel, and full of Criffel and Eskdale granite, carboniferous limestone, felsites, &c. At the lower part is a red sand. This drift is clearly the same as the 'upper wash' at Birmingham.

---

[1] Marine shells occur in a gravel on the river bank at the ferry, close to Shrewsbury.

[2] Possibly taken from railway ballast and therefore doubtful.

This is close to Stapleton, where are fine hummocks. Again at Walford[1] are fine hummocks, identical in shape with those of a modern moraine.

At Dorrington are boulders of Criffel granite, often 2 feet × 2 feet × 2 feet. At the station, looking north, the moraine-like mounds are well seen.

I return by train to Shrewsbury. The drift hill examined near Stapleton is opened for ballast for the railway, and is quite like a kame in shape. A hill of rock is rounded off as if a roche moutonnée. The region seems to be glaciated.]

Lilleshall

[At Foxhill Field, New Lodge Farm, Lilleshall,[2] is a ridge made of fine sand below, in the upper part of which are bands of a thick clay, resembling the india-rubber clay at California, except that they contain here many shell fragments.

Bands of sand and fragments of clay continue above this, and on top of all is the surface gravel full of Lake District granites and felsites.

The pebbles in the upper gravel are mainly Eskdale granite, syenitic granite, felsite and felsitic ash, and also many chalk flints out of the Irish Sea.

The stiff red clay occurs only in bands, and is clearly marine; it contains occasional chopped angular fragments and pebbles, and was made in a sea in which icebergs floated.

It is not so thick as at California, and seems to have been made at the close of the quartzose sand period.

The shell fragments in the interlaminated sand, and even in the clay, are often thin, brittle, broken, but not rolled.

---

[1] North of Dorrington.

[2] See paper by G. J. Woodward, *Brit. Assoc. Birmingham*, 1865.

The clay occurs tossed up in the upper part of the sand, as though carried there.

The Moel Tryfaen gravel corresponds with the upper 3 feet of surface gravel, having the same character, structure, and lithological composition, and being quite unlike the yellow marine (?) sand which also occurs here, and is full of rounded grains of quartz, like a sea-sand.

This is an important point. There is genuine marine clay at Lilleshall, but not at Moel Tryfaen. (So, too, genuine marine gravel occurs at Macclesfield Cemetery, but not upon the mountain.)

The drift at Lilleshall makes a ridge like a moraine or an old sea beach, being banked against an outcrop of old rocks, and protected by that outcrop.

For a description of the drifts here and about Wellington, see *Notes on the Geology of North Shropshire.* Charlotte Eyton. London, 1869.

The elevation of the top of this hill is 463 feet.]

Strethill, Coalbrookdale

[On the Severn between New Bridge and Buildwas are high hills of sand and of gravel. There is sand also at Buildwas. At Strethill, near Coalbrookdale Station, is a hill rising to 310 feet, composed, according to Man,[1] of 71 feet of sand, overlaid by 70 feet of boulder clay, on which lie 70 feet of sand and gravel.

We examine the sand and gravel pit on the side of the hill, and find a coarse, glacial gravel, the pebbles of which are mainly Lake District syenites, Eskdale granites, and Lake District felsites, with which are rounded pebbles of local rocks, including Pentamems limestone, Wrekin rhyolite, and Lugmyndian sandstone; also some chalk flints. There are 50 feet exposed, some loamy clay shown, and larger boulders of the same rock at the top.

---

[1] *Quart. Journ. Geol. Soc.*, 1864.

It is the same as the 'upper wash gravel' at California and at Lilleshall.

The hills of drift are heaped up high in knolls like a great moraine, which it very probably is.]

Wolverhampton

[From Wolverhampton I visit Bushbury Hill.]

For the distribution of erratics in the Midland district, see Reports of the Committee on Erratic Blocks, *British Association for Advancement of Science.* Drawn up by Dr. Crosskey.

On a Section of Glacial Drift at Icknield Station, Birmingham, by Dr. Crosskey, *Proc. Birmingham Phil. Soc.* vol. iii. p. 209.

[Bushbury Hill is a long ridge rising suddenly out of the plain. The north side of the ridge is covered by large boulders of granite, mostly from Criffel, and many from the lakes. This is the 'terminal concentration' spoken of by Mr. Mackintosh (*Quart. Jour. Geol. Soc.*, 1879, p. 425).

Many of the pebbles are scratched (?), although much of the deposit is more or less stratified and gravelly. Boulders of 'ash-rocks' occur, and also of many other materials. The gravel here is full of quartzite pebbles, which are probably derived from the conglomerate of the new red sandstone to the north. Possibly much of the gravel is merely a decomposed triassic conglomerate in place. There are no morainic contours here.

I now think (1886) that this concentration of boulders near Wolverhampton is not the terminal moraine proper, but is rather the edge of the fringe.[1]]

---

[1] See Rev. WILLIAM LISTER in a paper 'On the drift containing recent shells in the neighbourhood of Wolverhampton,' *Quart. Journ. Geol. Soc.*, 1862, p. 159. He speaks of travelled blocks of granite and greenstone on Bushbury Hill, and of the *shell bearing drift* at Bushbury Junction. These shells as determined by Dr. G. Jeffreys all now inhabit the Arctic Sea. They appear to have been cast up by the tide on a pebbly beach and were possibly carried by an iceberg. All but two are common British species.

Rowley Regis

[We visit the basalt quarries.

The basalt is cracked by decomposition on top and all around its edges, forming the so-called 'Rotch.' The 'Rotch' often shows concentric layers like the skins of an onion, forming a round boulder by weathering. I examine the supposed glacial striæ. These marks or furrows are only on decomposed rock, and on rock fragments near the surface. They are often curved, and usually start from an edge, being on angular faces like Ogham stones. Furrows cross one another. They are probably due to tree roots, or perhaps to the action of humic acid on the rock.[1]

No trace of drift or glaciation is seen. A local creep down hill brings angular fragments of the basalt down on top of the 'rotch.' At the Rowley Regis Station is an interesting gray sandstone, made out of the basalt by decomposition, undecomposed pieces of basalt remaining in it. Had glaciers or floods been over here, it would have been removed by them.

A proof that the furrows in the basalt were made by glaciers is said to be the fact (?), that they were made before the rock was decomposed. Since the decomposition layer was equally thick under the scratches as elsewhere, I find just the opposite to be the case, and that the furrows were made mainly *in* the crust, which was thinner under the scratches.

I collect specimens of these furrows on trap, which are identical with those near Spring Mill, Pennsylvania.

---

[1] On the markings on Trap see H. C. Lewis: Great Trap Dyke across Pennsylvania, *Proc. Amer. Philos. Soc.*; Pengelly: *Trans. Devonshire Assoc.*, vii., ix., xii., who describes cross markings on trap at Englebourne, near Totnes, Devonshire; Somervail: *Trans. Edin. Geol. Soc.*, vol. v., part 1, 1885, p. 87, who thinks the above are due to a plough.

Stourbridge to Six Ashes

3 feet ×	2½ feet ×	2 feet	Felsite (Keswick).
1½ foot ×	1 foot ×	1 foot	Lake District syenite (Buttermere).
,,	,,	,,	Criffel granite.
,,	,,	,,	Felsite.
,,	,,	,,	Lake District (?) slate.
,,	,,	,,	Silurian conglomerate.
,,	,,	,,	Syenite.
3 feet ×	2 feet ×	1 foot	Arenig (?) felsite.
1 foot ×	½ foot ×	½ foot	Quartzite grey.

This locality is about 100 feet above the Stour river. The stream of boulders coming down the Stour is a local one, stranded by icebergs.

It is the same set of boulders as those observed about Wolverhampton.

I have as yet found no trace of the supposed glacier that brought the Arenig blocks to Frankley.[1]

We go to Six Ashes—free from drift, but north and west of here, boulders at a much lower level are said to occur in abundance. Large granite boulders are seen in and about Bollington. Smaller ones are carried up to the top of the hill for road-metal, and often get into the fields. I picked up a Scotch erratic, 4 inches long, in a field at Six Ashes, but soon after found a similar one of *slag*. Instructive. No drift is on this high ground. It is the watershed between the rivers Stour and Severn. Evidence against submergence.]

Stourbridge to Alveley

[A drive over Bunker's Hill to Alveley Hill showed no traces of glaciation. There is an exposure of Bünter pebble-beds on Bunker's Hill, with pebbles showing pressure. On Alveley Hill, near the inn, on the roadside, I found several boulders of Arenig felsite planted among many other pieces of Rowley rag brought here.

---

[1] These observations were noted in October 1887, a few days *prior* to Professor Carvill Lewis' visit to Frankley Hill, with Dr. Crosskey, to which reference was made on pages lxv. and lxviii.—J. F. L.

Collected boulders 2 feet × 1 foot × 1 foot are on both the south and north sides of the hill by the roadside. Similar boulders are said to occur on Witherley Common.

We drive from the inn toward Higley Station, and in the side road opposite two deserted houses find some large fragments of Arenig felsite, being one mile east of Alveley Hill. Afterward, at a gate-post near Trehern Farm, north-west of Higley, we find another similar boulder, this being two and a half miles south of Stourbridge.

An examination of the Permian breccia at the new reservoir near here shows it to be made mainly of Uriconian felsites, and to contain no large erratics or Arenigs. We thus have found traces of the *trail* of Arenig felsites on the line between Frankley Hill and Wales. *This was probably the course of a very ancient glacier in the first glacial epoch.*[1]]

Birmingham to Wellington and Stafford

[I go from Birmingham to Wellington. At Hockley is a good exposure of red gravel lying on a flat surface of red triassic sandstone, the gravel being 6 feet thick. No 'till' is here, and the gravel resembles that of Philadelphia. At West Bromwich is an exposure of triassic sandstone overlaid by 10 feet of the same gravel.

Just west of Wolverhampton Station rock is exposed, with only a trace of gravel on top.

Before reaching Wellington Station we cut through the deep drift, full of clay and boulders. Wellington is built on the moraine. Boulders of granite abound in the streets.

Constitution Hill is a mass of drift. Sand with shell fragments also occurs here. The moraine runs then north-west of the Wrekin. Pebbles of coal occur in the sand. There is a mixture of erratics from Scotland and Wales.

---

[1] The observations between Stourbridge and Alveley were made just *after* the critical inspection of the Frankley Hill drift.—J. F. L.

I go to Stafford, passing inside of the moraine through a deep cutting; Hadley being north of the moraine, with a flat country to the north. From Hadley we keep on level ground until nearly reaching Newport, where are low hills (of drift ?).

Beyond Newport are hummocky hills of morainic aspect followed by outcrops of rock, and we again enter the non-glaciated area, the moraine being at Newport, though not well developed on the railway. There are several meres about Newport.

A great river flowed from Congleton, through Stoke to Stafford, Wolverhampton, Bridgnorth and Kidderminster.]

Stafford

[Criffel granite boulders are scattered all over the southern portion of the county.

A large one (4 feet × 3 feet × 2 feet) occurs in the yard of the White Lion Hotel, Stafford. Another, described long ago by Darwin in the *Phil. Mag.*, occurs at Ashley Heath. These all lie on the surface of decomposed rock, just as the boulders of the 'fringe' do in Pennsylvania. Is this a fringe? I now think that the concentration of boulders near Wolverhampton is not the terminal moraine proper, but rather the edge of the fringe. No striæ are known in South Staffordshire.

All the granite boulders that I have seen are rough and subangular, not smooth or striated.

Mr. Mackintosh says (*Quart. Journ. Geol. Soc.*, 1879, p. 447) that no striæ have been found farther south than the peninsula of Wirral.

I go northward to Trentham. Above Stone is a railway cutting through soft triassic red sandstone, with apparently no drift on the top.]

Trentham, Longton, and Stoke

[In the railway cutting at the first station south of Stoke I find what seems to be true till; being a clayey matrix full of striated and glaciated pebbles, with erratics of granite, limestone, and more frequently a greenish gray eruptive rock weathering white on the surface, and also many quartzites, and shales. I walk from Trentham to Longton, finding erratics all the way. The large boulders are mainly the dark, greenish gray, ashy, or porphyritic rock (from the Lake District or Arenig ?). There are exposures of till (?) in the suburbs of Longton. There is no drift on top of the soft rocks of the district, only a few scattered boulders. I strongly suspect now that the region is *not* glaciated. (Fringe ?).]

7. *DRIFT OF THE SEVERN, THE AVON, AND RUGBY*

REFERENCES

J. BUCKMAN, *Ancient Straits of Malvern.*

The Straits of Malvern were so called by Murchison, in his *Silurian System.* A line of drift leaves the river in Salop and goes northward into Cheshire. Cheltenham lies on marine sand. 'Northern drift' is abundant about Birmingham and Bromsgrove, Bredon being its 'farthest southern extension in any quantity.' Murchison describes this drift as having 'blocks diminishing gradually in size as they are traced from north to south' (*Silurian System*, p. 528), [i.e. from the moraine near Bridgnorth to the south. (The same is the case on the Delaware River, the drift at Easton being coarser than that at Philadelphia.)] An 'oolite drift' is local and atmospheric.

W. C. LUCY, *The Gravels of the Severn, Avon, and Evenlode, and their Extension over the Cotswold Hills.* The northern drift contains new red sandstone pebbles, Lickey quartz, millstone grit, coal measures, granite from Cumberland or Scotland, flint, chalk, &c., and is divided into:

(*a*) That at 750 feet on the Cotswolds, which is made chiefly of *quartzose pebbles.*

(*b*) That which contains *flints* and northern detritus and extends down to the mammalian beds.

(*c*) Mammalian drift, same composition as *b.*

(*d*) Terrace deposit 40 feet to 50 feet above the rivers.

(*e*) Valley drift with mammalian remains.

Oolitic gravel occurs high up on the hills. Subangular oolitic gravel at 500 feet to 700 feet was held by Dr. Hull (*Mem. Geol. Sur. Geol. of Country around Cheltenham*) to be a sea-beach.

The gravel at 700 feet on the Cotswolds about Nympsfield, consists (p. 37) of some quartz pebbles. At Mickleton Tunnel, the summit of which is 490 feet, is a great thickness of drift, this thick drift being at 350 feet to 420 feet above the sea.

'No large boulders or boulder clay have been found on the high ground of the Cotswold Hills' (p. 41), being only met with in the valleys. Fragments of millstone grit and quartzose pebbles are present in the high level gravel, but chalk flints are absent from the height at which gravel is first met with down to about 100 feet (p. 41). At Mickleton Tunnel, &c., the gravel is varied, and large patches of chalk and flints occur in it, as if icebergs were present.[1]

About the Valley of the Severn

Shells are seen in the gravel at Willey Park, near Broseley, at 460 feet above the sea or 360 feet above the river, being the highest point where shells or drift occur (the deposit of boulders at Burton near Much Wenlock at 800 feet being morainic). The shells at Strethill are at 300 feet, and all other marine gravels are below 300 feet, Frankwill and Shrewsbury being 280 feet. Mammalian remains occur as high as 270 feet at Malvern, thus indicating fluviatile action. The sands and gravel of the Severn Valley show a marine submergence up to 300 feet, while the Avon deposits indicate fresh-water rivers. An arm of the sea extended up the Severn to the 300 feet contour-line, and floods and rivers washed into this estuary mammalian remains and old gravels. As the land rose, the Avon and Severn restratified, brought down, and partly cut through the deposits in their valleys. (The marine fauna of the Severn Valley, as pointed out by S. V. Wood, Junr., is quite different from that of the middle glacial sand of East Anglia. It is separated from it by high level unfossiliferous deposits, but Jeffreys said that it was like that of Moel Tryfaen, Wolverhampton, and Manchester.)

---

[1] See also Hull, 'Physical Geography and Pleistocene Phenomena of the Cotswold Hills,' *Quart. Journ. Geol. Soc.*, 1855, p. 477.

T. G. B. Lloyd, On the Superficial Deposits of the Avon and Severn Valleys and adjoining Districts. *Quart. Journ. Geol. Soc.*, 1870, p. 202.

(See also a valuable paper by Strickland in Sir W. Jardine's *Memoirs of H. E. Strickland.*)

The highest drift about the *Valley of the Avon* is from 430 feet to 300 feet above the sea, and consists of a flinty gravel sometimes overlying a clay (made as described in the last paper), which contains striated fragments of lias limestone, white chalk, and occasional blocks of syenite: below this is the 'general quartzose drift' of Strickland, or the 'northern drift' of Murchison.

At a lower level below 300 feet are gravels and sands made mainly of local materials, and sometimes containing marine shells, due to an estuary opening southward; also fresh-water deposits.

J. M. Wilson, On the Surface Deposit in the Neighbourhood of Rugby. *Quart. Journ. Geol. Soc.*, 1870, p. 192.

Rugby plateau is at an average height of nearly 400 feet, and is covered with clay and gravel. The clay is a 'reformation' of the underlying lias clay, and contains *scratched* stones, of liassic limestone, chalk and flint [the striæ due to aqueous action and made in place?]. The valleys contain deep sandy deposits, with occasional mammalian remains, as if due to river action.

(Returning to Manchester, Professor Lewis travelled back to the central districts of England, taking a route lying more to the south-east.) (*See* Map VI. p. 167.)

Manchester to Nottingham

[A nearly level drift plain extends from Manchester to Heaton Mersey, the drift being clayey and often stratified. At Heaton Mersey are some low ridges of drift, and hills with morainic contours, filled with boulders, occur just before reaching Stockport. At Stockport are exposures of pale red Permian or triassic sandstone, with drift lying on top. (Examine this; good exposure on the Midland Railway.) Exposures of coarse stratified gravel occur just beyond Stockport, and large hummocks are seen less than one mile beyond the town. These drift hills are as finely heaped up as in the terminal moraine at Metuchen in New Jersey. They rise to 100 feet or more, are a mile wide, and contain large boulders. Immediately beyond these drift hills the rock outcrops, we pass through a tunnel, and no more drift appears. Large quarries follow, showing no drift at all.

This, then, is clearly the terminal moraine, develope precisely as in New Jersey and Pennsylvania, and magnificently shown. The line of demarcation between th glaciated and the non-glaciated district is clearly marke and precisely defined. The moraine has the same widt and height and contours as it has in New Jersey an Pennsylvania. More drift [1] occurs at points beyond.

A huge hill of stratified drift occurs one mile befor reaching Bugsworth. Although there are numerous outcrops of rock with no drift upon them, hills of drift and patche of drift are occasionally seen along the valley about here.

Beyond Bugsworth I see no trace of drift until w reach low ground at Derby. There are fine exposures c carboniferous limestone (mountain limestone) about Miller's Dale; beyond this of Yordale shale, and farther on, of millstone grit, all with no trace of drift. At Derby we reach the low flat region of the trias, where gravels and clays probably occur. Stratified gravel is exposed at Borrowash. This region is like the York Plain. Elevation 45 ± feet. A perfectly level alluvial plain extends from Derby to Trent, and then on to Nottingham, covered by the Philadelphia red gravel. There are no till hills or traces of glaciation.]

---

[1] The fringe or the moraine.

Nottingham

[Hills of soft Bünter sandstone rise here, and are excavated for caves, catacombs, &c. Boulder clay is said to occur here and there, as if dropped by icebergs, and large boulders are seen. Glaciated boulders occur in the boulder clay. I saw one of carboniferous limestone. There are also boulders of Lake District trap and ash and large pebbles of flint, &c., from the north-east. A current clearly came from the north-east, as boulders are stranded on the east side of the hills. A mass of till at Stanton was probably dropped by an iceberg caught here whilst drifting south-west. No rock striations are known in the neighbourhood. I am now convinced that till (boulder clay with striated boulders) can be made by icebergs. It differs from true till in having stratified sand and gravel, often both, above and below it; and in containing stones, some of which have been carried from the ice-sheet, while others have been picked up on the way by floating icebergs. The *contortions* in this boulder clay are characteristic of iceberg action, and are not seen in a glaciated region. As Mortimer (see *Yorkshire and Polytechnic*, vol. vii. p. 373) has shown, the boulders in the iceberg till usually *stand on end*, showing that they were dropped through some depth of water from an iceberg into the mud which had already settled at the sea-bottom. Icebergs could not get down the Delaware River so easily as they could come from the broad sea to Nottingham. The land was probably depressed not much over 200 feet.

Older and higher gravels, old sea-beaches (tertiary) are said to occur in patches on the hills near Nottingham, facing the German Sea (Bryn Mawr gravel).

There seems to be evidence of a first glacial epoch in the Nottingham district.]

R. M. Deeley (The Pleistocene Succession in the Trent Basin. *Quart. Jour. Geol. Soc.*, 1886, p. 437), speaks of 'oldest Pleistocene deposits' distinguishable from those of later age by their freedom from cretaceous rock débris. [As if *local* glaciers occurred in the Pennine Chain long before the advance of the Scandinavian glacier; just as they did in Wales, as Reade showed, and as the Frankley Hill erratics show.] He makes these early Pennine deposits belong to a distinct epoch, marked by physical changes at its close.

[I go to Hucknall to examine the drift and erratics on the hills west of that place at about 600 feet.

Part of these are described in *The Geology of the Country around Nottingham*, by W. J. Aveline. 2nd ed., 1880, pp. 38 and 39.

I go to the 'Long Hills,' one mile and a half west of Hucknall Torkard Station.

In a brickyard at the base of the hills is an exposure of red clay free from pebbles below, but covered by a yellow clay with pebbles out of the Bünter sandstone in it.

All is stratified, and no large boulders occur here.

Farther on in the fields south-west of Misk Farm, some 200 feet above the station, I find boulders of Buttermere (?) syenite, carboniferous s.s., and hornblende syenite.

These measure at least one foot each way.

Here also, in the valley on the south-west side of Annesley Park Springs, are two large fragments, each 4 feet long, of carboniferous s.s. This is in a valley opening to the south-west.

These have not come far.

But on top of the hill, in the road through the field, at an elevation of 260 feet above the station by barometer

(578 N. Ordnance Survey), are boulders of dark felsite and hornblende syenite.[1]

In Annesley Park, on a hill between the pond and the gatekeeper's house is an exposure of loamy yellow clay in which are boulders of Permian s.s., granite, &c. The granite is coarse-grained and red, and is 1 foot × 1 foot × 1 foot.

At the entrance to Park Hall Farm, at the corner of two roads near a barn, is a boulder of carboniferous s.s., 3 feet × 3 feet × 2 feet. About 100 yards farther, on the other side of the main road going north, is a boulder 1 foot × 1 foot × 1 foot, of black trap (Derbyshire loadstone or Cleveland dyke). Still farther on, before reaching Robin Hood Cabin, is a boulder of very brittle black trap by the roadside, closely resembling that from Iron Crag, near Keswick.

A new road cutting to Annesley Station near Annesley Church gives an excellent section of soft triassic sandstone, overlaid by 1 to 2 feet of yellow loam. No till whatever is seen.

At Robin Hood Inn, Annesley, at the corner of the road, is a boulder of Lake District porphyritic felsite, 3½ feet × 2½ feet × 1 foot.

There is also a smaller one of hard sandstone.[2]

The whole occurrence reminds me of the Bryn Mawr gravel of Pennsylvania, which like this contains large iceberg-carried boulders, but is itself pre-glacial, Does this indicate a submergence of 500 feet in pre-glacial (or first glacial) times? I return to Annesley Station. No limestone and no chalk occur in this old and thin drift.

Blake has found Permian fragments in the Annesley neighbourhood,[3] which came from the west, from lower down, but at Blidworth he found lias fragments which came from the east. Local rocks are larger and more angular in these deposits than those from the Lake District. My collection of the latter is not like the collection I made in the Manchester District. Those at Annesley came from the east side of Scaw Fell and over the Stainmoor Pass.

---

[1] This felsite is identical with that from Falcon Crag near Keswick.

[2] Also near here, an erratic, Whin Sill?

[3] These belong to an old triassic conglomerate, and are not drift according to Shipman.

The collection of boulders at Annesley is quite different from that at Strines and New Hills.]

R. M. DEELEY. (The Pleistocene succession in the Trent basin. *Quart. Jour. Geol. Soc.*, 1886, 437.) He makes out a complicated series of drifts, and of ice-flows and submergences. [In reality the facts he produces appear to point to a marine submergence of no great depth in which icebergs floated.] This was preceded and followed by fresh-water terrestrial action. The submergence brought the 'chalky boulder clay' and shoal currents from the north-east. Charnwood Forest was an island surrounded by an ice-belt, and this breaking off distributed the Charnwood rocks in all directions, such as south-east to Aylestone (p. 452), and north to Thringston (p. 479). [This northward dispersion is proof of *icebergs*, or of sea-ice, not of glaciers.] Mr. R. Brown (Physics and Arctic Ice. *Quart. Jour. Geol. Soc.*, 1870, p. 680) says, 'It is a mistake to suppose that bergs found in the south must all have come from the north. The winds and currents waft them hither and thither until by the force of the waves they break into fragments. A mixture of erratics from all points is proof of iceberg action, not of glaciers.'

Mr. Brown, in speaking of the 'ice-foot' in Davis Strait (*Quart. Jour. Geol. Soc.*, 1870, p. 689), says that, as land-slips occur in the summer thaws, earth, gravel, and avalanches of stones come thundering down on the ice-foot, there to remain until it breaks off from the coast and floats off to sea with its raft-like load of land débris.[1]

[A study of Deeley's paper leads me to think :—

(1) That there was a first epoch of glaciation when the glaciers originated in the Pennine or other British hills,

---

[1] The collection of boulders at Annesley is quite different from that made about Strines and New Hills.

and spread their débris over the surrounding low lands (p. 454). This was a period when Wales, the Pennine Chain and the south of England stood much higher than they do now. There was an elevation of mid-England, with perhaps a depression farther north.

(2) Mid-England sank and the glaciers disappeared. Did a submergence now occur of 500 feet at Nottingham?

(3) Mid-England being some 200 feet lower than it is now, the Irish Sea glacier and the North Sea glacier advanced to the points marked by their moraines.

(4) Marginal lakes were now made, that in the east of England being 400 feet deep, and the chalky boulder clay was laid.]

Deeley says, 'The Pennine Chain was much lower during the Middle Pleistocene epoch (that of the chalky boulder clay) than it was when the older Pleistocene boulder clays were formed, and the great chalky boulder clay advanced into the partially submerged area of the Trent basin.' He says the great chalky boulder clay is generally a true ground moraine, but in some places, as at Chellaston, Melton Mowbray, Market Bosworth, Abbots Bromley, &c., it presents indubitable signs of aqueous action. Chalky boulder clay extended up the Trent valley to Hanbury, north-west of Burton-on-Trent, and another arm went to Leicester, but was divided by the Wreck, and does not occur in the Ashby-de-la-Zouch coalfield, which was sheltered by high land to the east and north. Here the chalky clay is a silty deposit with a few flint and quartz pebbles. There are striæ in Stanton Tunnel E.N.E. (pp. 458 and 461). The glacier which made the chalky boulder clay, according to Deeley, advanced on a submerged area. Over the clay is often a chalky gravel, which may contain rolled boulders of chalky boulder clay. This gravel occurs in the Ashby-de-la-Zouch coalfield. The most north-west point where chalky gravel was noticed was at Biddulph, near the station. The sand which contains layers of coal and shell fragments occurs at Congleton. The shelly deposits near

Wolverhampton are held to be the same gravel. The contortions in the clays he believes to be due to a third series of glaciers (p. 473).

Quartzose sand (older Pleistocene) occurs at high levels at Blackwall E.N.E. of Gelston on a hill top, six miles north of Grantham.

Derby

[At Spondon (a village west of Derby) I examine in a brickyard a genuine till, full of glaciated Pennine rocks. Coal shales, limestone, and sandstone occur here; often large boulders and well-striated fragments, including many sharp ones. This has come down the Wye and Derwent Valleys. Near Charnwood Forest is black marble from Bakewell. This Pennine till, older than the chalky boulder clay, extends to near Leicester, and covers the hills about Long Whatton and Sheepshead, being sometimes 60 feet deep. The erratics are purely local out of the Derwent or Wye Valleys.[1]

(Deeley says that till with striated erratics occurs near Matlock Bridge, at Riber Castle Hydropathic Establishment.) I find black bituminous limestones (with carbonate of iron, and a very small pebble of red granite) probably derived out of an older deposit.

We examine a red gravel, often contorted, at Borrowash. This is the second river terrace, and forms a plain some 30 feet above the river, being perhaps like the Philadelphia red gravel. Another inner and lower gravel is fresh and not contorted. Deeley thinks that the contortions of this red gravel, and of all the gravel higher up, are due to a glacier. I disagree with him and think them due, either (1) to creep, (2) to humic acid infiltration, or (3) to flood action.

We visit a gypsum quarry near Aston-upon-Trent on higher ground. Here the great chalky boulder clay[2] lies upon the Keuper.

---

[1] The Pennine till was probably made in water bordering local glaciers.

[2] I see that this till is not the great chalky boulder clay, but the Pennine

The clay is full of chalk, flint, and striated carboniferous limestone, being a till. It is overlaid by a chalky gravel. Till, 12 feet thick, is overlaid by 6 feet of gravel.

It is not a true till, but a tough clay filled with glaciated fragments. This is the most northern outlier observed of the great chalky boulder clay.

It is clearly *aqueous*, and was made in a *lake* in which the glacier ended, as Deeley agrees with me. In the Ashby-de-la-Zouch coalfield it is represented by a silt 60 feet deep, pure and light, containing a few flints, which is a true *loess*. Thus chalky boulder clay passes here into *loess*.

At Aston-upon-Trent this chalky boulder clay rests upon a thin deposit of Pennine till, which latter rests on an old red Pennine sand, the quartzose gravel extending up to some 500 feet or more. It can be followed north to between Lincoln and Newark (where it is quite free from flint and chalk) as far south as Leicester, and east to a few miles north-west of Burton-on-Trent, and occurs capping the hills and underlying boulder clays. It is of the same age as the Pennine boulder clay. Marine (?). The Pennine boulder clay is both above and below this gravel.

The Charnwood Forest dispersion was by means of coast ice, and was *before* the period of the chalky boulder clay.

Chalky sand extends up to the top of the Blidworth Hills, where it was shallow, temporary, and thin, traces of it only occurring at this high level, 500 feet.

The Pennine boulder clay near Leicester also changes into silt and into gravel just as the chalky boulder clay does; and at Leicester this Pennine silt is overlaid unconformably by chalky boulder clay. Nowhere do the Pennine deposits pass into the chalky boulder clay deposits; but these latter unconformably overlie the former. It is an admirable example of two glacial epochs.

---

boulder clay with a trace of chalky boulder clay and chalky gravel on the top. Chalky gravel is a shallow-water lake deposit, representing the edge and end of the chalky boulder clay deposit.

We examine a cutting in the red gravel at Weston-on-Trent, being the highest river terrace, 74 feet above the river. This gravel is the oldest, and first formed after the departure of the *chalky gravel* submergence. It has many flints. It is contorted and alternates with red sand. The contortions were made by the passage of a glacier over it, according to Deeley. Is it not the 'trail of the warp'? To what are the contortions due?

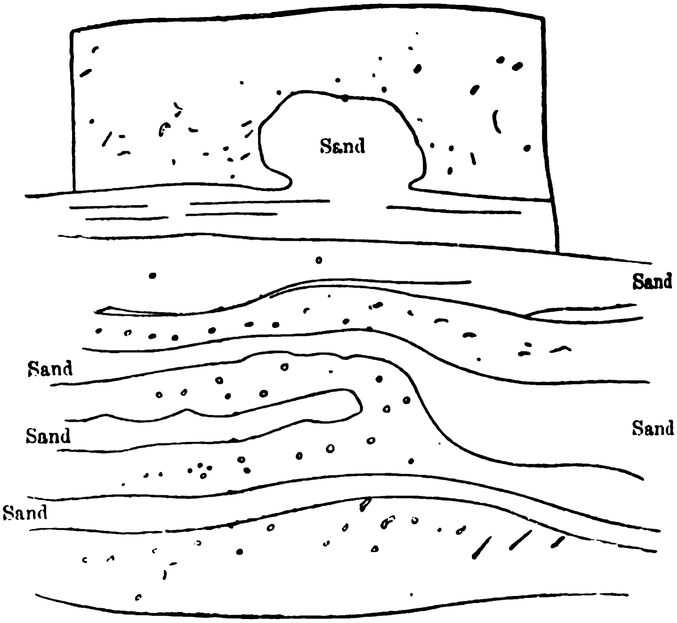


FIG. 36.—Cuttings in Red Gravel, Weston-on-Trent, 74 feet above the river.

We now go to the highest point south of Derby, Chellaston Hill (the Tuppa), 256 feet, where there is a fine clean sand and gravel with flints and bits of chalk. This lies on chalky boulder clay, which is here some 50 feet thick. It was a sandy shoal in the great lake, which, Deeley thinks, was brackish, and contemporary with the marine submergence of 350 feet ± in the Cheshire Plain, which made the shell gravels at Biddulph, Keele, Little

Madeley, Eccleshall, Wolverhampton, and Bridgnorth, which are true sea beaches according to Deeley.

We visit a gypsum quarry at Chellaston, where over the Keuper are: (1) Clay with pebbles and angular rocks; (2) Thin layers of sands with flints; (3) Chalky boulder clay, full of flints, chalk pebbles, fragments of lias, striated limestone, and striated quartz.

We then visit Sheldon Wharf brickyard, where there is a fine deposit of Pennine boulder clay, containing striated erratics. These are different from those seen at Spondon. Here the limestone is white and crystalline, and I find a boulder of Lake District felsite. This flow, therefore, came down the *Trent* and the Dove, not the Derwent. Lake District erratics also occur at Burton-on-Trent.[1]

Chalky gravel is found high up on the hills north of Skeffington, as at Tilton-on-the-Hill.[2]

I go to Market Bosworth to see on a road leading north out of the town the loess (representing the chalky boulder clay) overlaid by chalky gravel. There is a pit on St. Ann's Hill.

Granite is said to occur about Ambergate. (See the *Survey Report.*)

I go to Leicester Abbey and to Aylestone. Charnwood Forest boulders lie *under* the chalky boulder clay and also under the Pennine clay, being an older dispersion made during submergence, and they rest upon the quartzose sand. The latter occurs at Gelston Hill, south of Lincoln, free from chalk. We pass close to it at Ponton. South of Grantham chalky gravel is seen. This sand is current-bedded, showing a current from the west; hence its freedom from chalk, though so close to the chalk hills of Lincolnshire. No foreign erratics are in the Dove Valley. Erratics of granite occur at Millers' Dale. (See Geol. Map.)

---

[1] Probably the Lake District boulders came from the Irish Sea glacier, south of Macclesfield, which floated down by way of Leek, Uttoxeter, and Burton.

[2] At 500 feet ±. See Judd, *Geol. of Rutland and Leicestershire.*

At Sibbertoft and Kilworth, north-east of Rugby, there is a great thickness of chalky boulder clay. This is high ground, 500 feet or more. It is the moraine (?) of the greatest extension of the chalky boulder clay glacier.]

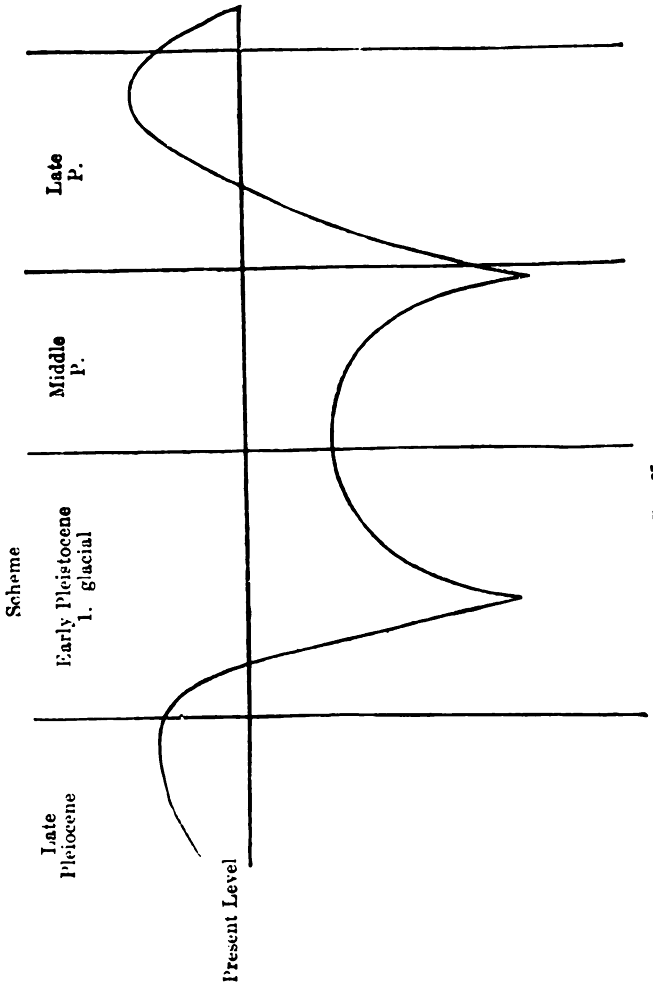


FIG. 87.

Deeley says (p. 464) that the stratified gravel on the high ground north-east of Rugby was very temporary.

The marine submergence is shown by the shells at Biddulph. (Visit the large pit here.) The edge between *sea* and *lake* was along the watershed through the west of Newcastle to Ashley, and west of Eccleshall; then on to Blymhill, west of Codsall, west of Wolverhampton, and from thence along the east side of the Severn Valley. Salt-water ran down the 'Straits of Malvern.'

At Caldon Low are great beds of pebbles, and huge blocks of limestone, making a great *moraine.* (See paper 'On the Drifts of the Weaver Hills,' E. Brown, *British Association, Nottingham.* Burton-on-Trent, 1866.)

[The quartzose sand submergence was that probably in which the boulders were carried to Annesley Park.]

The land was submerged from 200 feet to 500 feet continuously through two glacial epochs. The elevation came *later,* which made the buried river valleys.

[As the shelly gravel of Cheshire, Wolverhampton, &c., occurs *below* the boulder clay (iceberg and lake carried), the Irish Sea glacier advanced into a submerged area.]

Trent to Sileby (Mount Sorrel)

[South of the Trent are hills of trias nearly free from drift. The gravel seen here is greatly due to the decomposition of a triassic conglomerate, I think.

As glaciated surfaces are said to occur near Mount Sorrel in the Charnwood Forest District on granite, I visit the spot. The granite underlies the trias unconformably, some knobs of it being exposed through denudation. Naturally such knobs would be rounded in outline, and perhaps waterworn.] Harrison (*Geology of England,* p. 160) says 'Great sheets of ice swept over the Charnwood Hills, rounding them,' &c.), while Blake thought it was a local glacier that had striated them and scattered boulders to the south.

[From Trent to Mount Sorrel the ground is low. Sileby is only some 70 feet above the sea, the village of Mount Sorrel is about 50 feet higher, and the 'mount' of eruptive granite or syenite rises to 125 feet above this. There is no drift on the top of the mount. On the flat ground west of the large quarry the granite is decomposed for 6 feet or more below the surface.

On the south side of a small ravine on the north side of the quarry, the granite is rounded and waterworn. The rounding of the granite[1] resembles glaciation, and it is not surprising that it has been mistaken for a glaciated surface.

It differs from a roche moutonnée in that the rounded surfaces are re-entrant or scalloped, and also in that the more compact portions of the granite stand out like ribs, both being the result of water action. I thought that on one or two surfaces I detected short, faint, irregular striæ, bearing about east and west. These may be due to the scraping of an iceberg, but I cannot speak confidently as to this. There are no flat polished and striated surfaces such as occur on the granites of Scotland and of Galway. Abutting almost against the granite, separated only by a few feet, is a mass of chalky boulder clay, perhaps 15 feet or more in thickness.]

Hill and Bonney, in a paper on the Precarboniferous Rocks of Charnwood Forest (*Quart. Journ. Geol. Soc.*, 1878, p. 230), say that the face of polished rock at Sopewell Quarry, near Sapcote, regarded by Harrison as glaciated, and photographed by him in his *Geology of Leicestershire*, is not a glaciated surface. They think it may have been rubbed by sliding sand.

[That most striæ are made by sand I learned at the Grindelwald glacier.

The striæ at Cork, I am inclined to think, were made by sand and water.

---

[1] *v.* W. J. Harrison, *Geology of Leicestershire*, for a description of the glaciated surfaces about Charnwood Forest.

The smoothing of the granite is probably due to the passage over it of *water filled with gravel.*

The traces of striæ could thus easily be made. I suspect that the striæ on the limestone at the Stanton Tunnel (*Quart. Journ. Geol. Soc.*, 1886, p. 461) are due to the same cause.]

That it is possible for floating ice to striate and polish rocky banks is stated by Ramsay (*Quart. Journ. Geol. Soc.*, 1862, p. 186) when he says: 'Marks of glaciation lie low down on the sides of the Moselle, where the floating down of the river ice has frequently rounded, polished, and striated the rocky banks in the direction of the flow.' But, as he farther states, there are no signs of glacial drift in the Valley of the Moselle, or in the Eifel, or about Bonn. Sir William Logan has stated 'that shore-ice in Canada charged with boulders has been known to produce grooves on the face of cliffs as well marked as those of glacial times' (*Quart. Joarn. Geol. Soc.*, 1872, p. 395). See also Forschhammer in Lyell's *Principles*, p. 231-2. For other cases of iceberg striæ see Bermot (*Z. D. G. G.*, 1879, xxxi. p. 145).

[This clay contains rounded pebbles of chalk and flint in abundance, also cretaceous fossils, lias, &c., all having come from the eastward. The boulder clay was deposited by the same agents, marine currents and icebergs, which smoothed the granite. It is an interesting locality. Boulders and pebbles of the granite are said to be scattered to the south of here, perhaps by icebergs.[1]

The terminal moraine probably goes southward from Stockport, viâ Macclesfield, Stafford, Wolverhampton, and Kidderminster (the latter place being south of it). Everything observed supports my former conclusion.]

---

[1] Some of the reputed large boulders of granite south of here may be really isolated outcrops of granite in place, as such occur, according to Harrison's *Geology*, p. 153, at Enderby Croft, Stoney Stanton, Narborough, and Sapcote.

Leicester

[West of Leicester Abbey are some hummocky hills made of Keuper marl, covered by sand and clay. In a large pit (Hack's Sand Pit) is an admirable exposure of red fine sand overlaid unconformably by tough boulder clay.

The sand is fine, but with gravelly layers, and has beautiful false bedding showing currents from the north-west.

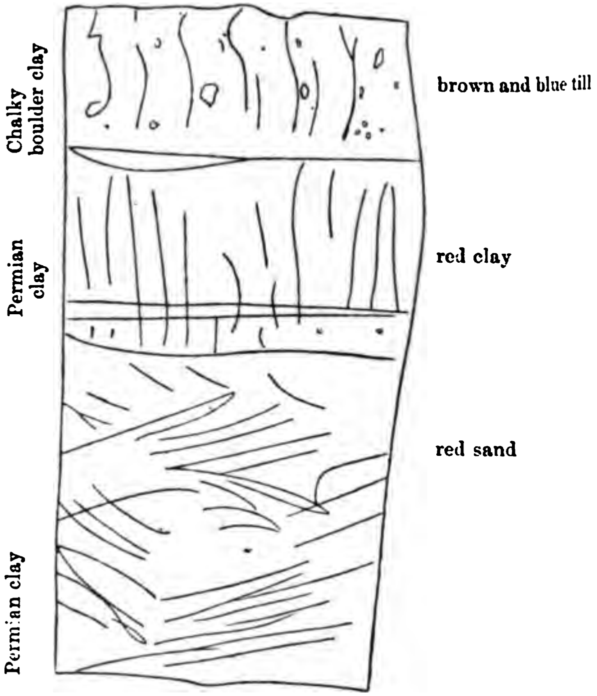


FIG. 38.—Section of Clay in Hack's Sandpit, west of Leicester Abbey.

The dips are toward the south-east, and are cut off by successive waves. The small ends of the faces are toward the north-west.

The sand contains much coal, coal being light, and easily carried with sand. The sand also contains numerous angular pieces of fossiliferous lias rock, fossil shells, and many broken shells. The latter are in small yellow fragments, and include scraps of encrinites or star-fishes (what are these?). No flint or chalk was observed in this sand.

On top of the sand there is a boulder clay. This deposit has several layers of sand at the bottom, and the clay is red below, and clearly stratified, and is free from striated erratics. The upper part is blue, and contains larger stones than the lower portion, and striated erratics occur in it.

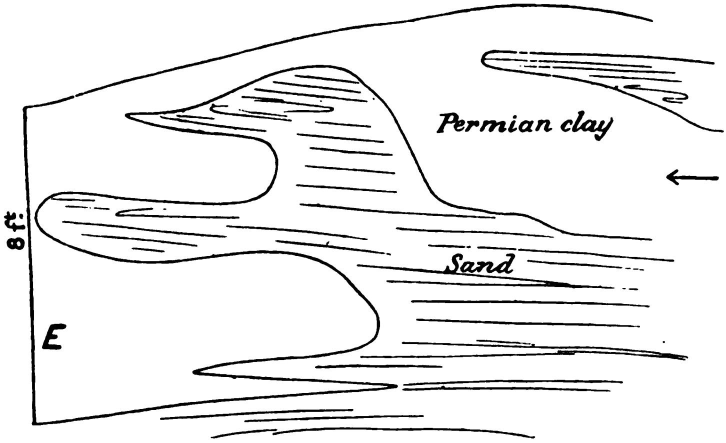


FIG. 39.—Section of contorted Sand-bed, Hack's Pit, west of Leicester Abbey.

Sometimes a layer of sand lies between the upper till-like clay and the lower clay. I took one piece showing the contact of the two clays.

The lower clay is purple, the upper is brown with blue joints, and contains striated erratics.

I see no flints or chalk in the lower clay, but chalk occurs in the upper. The upper, therefore, is the chalky boulder clay, and the lower the Pennine clay. The Pennine clay here is purely aqueous, and not made by a glacier, but the chalky boulder clay was made either by a glacier or by a lake in which there was a glacier. There are here fine examples of contortion, by which the sand has been pushed out in long fingers toward the south-east. (Fig. 41.)

This might readily be supposed to be glacial pushing, but I think it is due to currents depositing heavy mud, and occasionally sand. This is the explanation of many contortions where sand and clay come together.

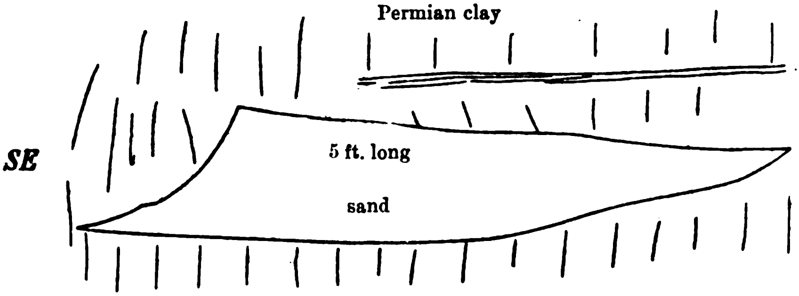


FIG. 40.—Section of Sand in Hack's Pit, west of Leicester Abbey.

The above for example is a mass of sand cut off by heavy clay, being just such action as I have now been examining in the sand. The direction is the same, and the form is the same. Is not the cause the same?

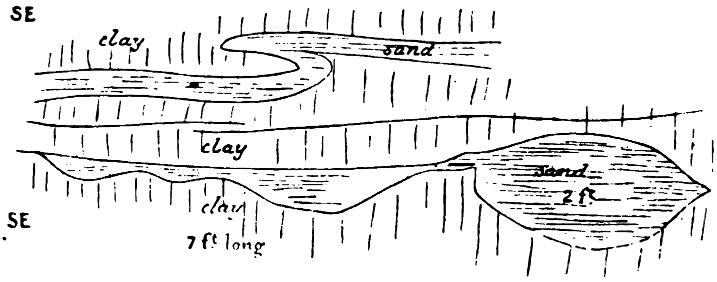


FIG. 41.—Section of Sand in Hack's Pit, west of Leicester Abbey.

The larger blocks in this Pennine clay lie dipping to the north-west.

There are no flints in either clay here. The upper clay, although containing white chalk-like fragments, may also be a Pennine boulder clay, and the supposed chalk may be a decomposed limestone.

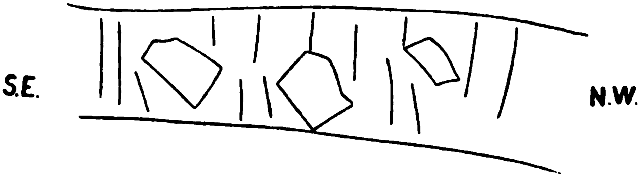


FIG. 42.—Blocks in Pennine Clay, Hack's Pit, west of Leicester Abbey.

The absence of moraine-like aspect in this Pennine clay is in contrast to its character at Derby. So, too, this chalky boulder clay at its edge (as near King's Langley) loses its morainic character, being far away from the glaciers.

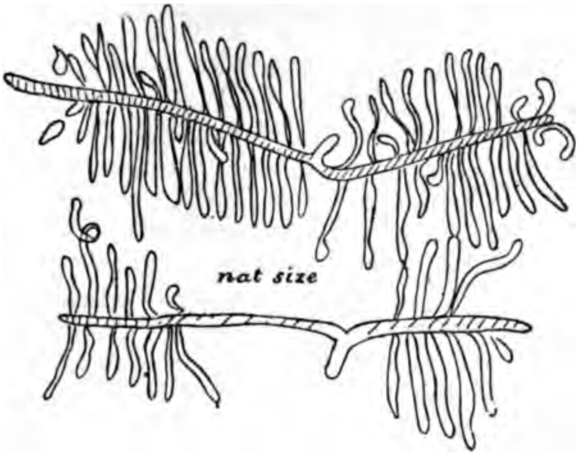


FIG. 43.—Worm Burrows in Sand in Hack's Pit, west of Leicester Abbey.

Near here an opening shows the stratified sand overlying Keuper marl, and on top of the whole is a loam containing some flints.

The sand above described is Deeley's 'Quartzose Sand' (see his paper, p. 446). I now go to Aylestone, three miles south of Leicester, where, on ascending to the top of the hill, I see a fine section exposed in a sand pit. Here, also, the same sand is overlaid by boulder clav.

The sand is light coloured, and well false-bedded, showing motion from west-north-west. It looks like a sea sand.

It contains coaly streaks, fragments of gryphea, and other smaller shells. (See Deeley, and *Trans. Leicester Lit. and Phil. Soc.*, 1882-3).

Gryphea and other fossils are common. It is 15 feet thick, and is overlaid unconformably but quietly by a tough red boulder clay, full of large and angular boulders of sandstone, Charnwood Forest hornblendic granite, limestone, &c. The granite is very abundant in large rectangular blocks embedded in clay, but is not striated or smoothed.

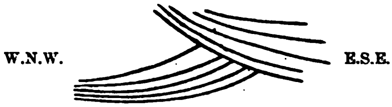


FIG. 44.—Section of Sand at Aylestone, near Leicester.

I found also a bivalve shell in the clay. All the angular blocks, except a few of sandstone, are of one variety of granite. This is the same Pennine boulder clay, and the angular blocks of Charnwood granite are excellent examples of iceberg work. As in the other quarry, the upper part of the clay is brown with blue partings, and contains striated limestones.[1]

It becomes columnar as it dries. In this the 'Rutland sand banks,' or Beasley's sand pit[2] I find striated erratics of bituminous limestone, and of lias or Permian fossiliferous limestone. A large Charnwood granite boulder, a cubic yard in measure, lies on the road opposite the three-mile post from Leicester. Deeley is wrong in saying that two deposits occur here, the chalky boulder clay forced over the Pennine clay

---

[1] A second visit here showed clearly two separate clays. An under one, red without glaciated stones as a rule, sedimentary, with no chalk flint, but with large angular blocks of Charnwood Forest granite. On this is the blue and brown clay containing more stones, among which are occasional chalk flints and chalk pebbles, more till like in aspect, but without large blocks of granite, &c. Chalk flints are very scarce in it. A sharp line, well seen at some distance, separates the two clays.

[2] See Deeley's paper, p. 452.

The Charnwood Forest erratics were dropped upon this hill as the icebergs grounded. I go south to Blaby Wharf which is at a lower level on the canal.

Here an old digging shows a clay full of limestone, sandstone, and a Lake District *felsitic ash erratic,* also

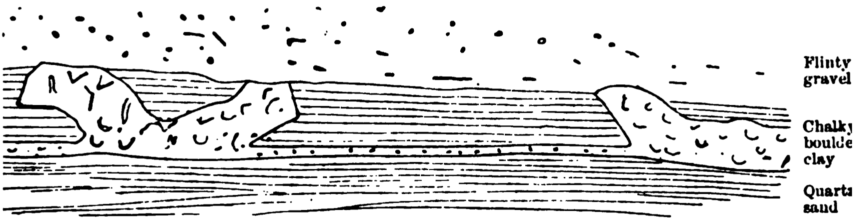


FIG. 45.—Section of Great Chalky Boulder Clay, near Blaby Wharf

Charnwood granite; the limestone is striated. This has all come down the valley.

Over the clay is 20 feet of flinty gravel, sharp flints forming the most of it.

In an adjoining pit is an excellent section.

Underneath is a fine sand, free from pebbles, and with no flints, showing by false-bedding currents from the northwest. Over it is a thin layer of clay (tough boulder clay), about an inch in thickness, which is sometimes absent and sometimes in lumps and irregular pieces a foot or more in diameter. In this clay, I find bits of flint showing it to be the great chalky boulder clay.

On the jagged top of the clay lie 20 feet of flinty and chalky sand, showing by false bedding that the current came from the *east,* and not the *west.*

The flinty gravel is coarse, such as I saw west of Louth. Do all the Pennine and the chalky clays belong to the same epoch? Opposite currents are also seen in the chalky gravel and a fragment of chalky boulder clay was found in it.

The gravel flood has washed the boulder clay away here and the chalky boulder clay and Pennine clay run into each other.]

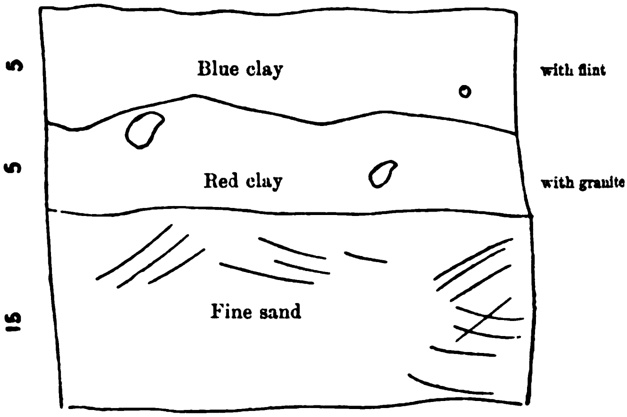


Fig. 46.

---

8. *EAST OF ENGLAND*

References

T. McK. Hughes, The Post-Tertiary Deposits of Hertfordshire: Elsden. *Transactions Hertfordshire Nat. Hist. Soc.*, March 1, 1881. On the two Plains of Hertfordshire and their Gravels. *Quart. Jour. Geol. Soc.*, August, 1868.

A. J. Jukes-Brown, On the Southern Extension of Hessle Boulder Clay into Lincolnshire. *Quart. Jour. Geol. Soc.*, August, 1879, p. 397. (Excellent paper.)

W. H. Penning, Notes on the Physical Geology of East Anglia during the Glacial Period. *Quart. Jour. Geol. Soc.*, 1876, p. 191. He holds all the boulder clays to be due to the melting of icebergs. Only *one* submergence is indicated; 'a gradual and long-continued movement of depression was succeeded by another equally gradual one of re-elevation.' The glacial series is continuous, the gravels being subsequently washed out of the boulder clay by the retreating sea. The 'Middle glacial' at Cromer is only blown sand (Jukes-Brown).

C. Reid, The Glacial Deposits of Cromer. *Geol. Mag.* vii. 1880, p. 55.

Thinks a glacier, starting in Lincolnshire on the chalk escarpment, flowed from a point *north of west* to Cromer.

Woodward, I believe, thinks that Reid's 1 and 2 till should be included in the term 'Cromer till,' and that all the pre-glacial beds on the coast should be called the 'Forest-bed series,' viz.:—

Lower Glacial Series	Contorted drift	
	Cromer till	Upper till Middle sand Lower till
Forest Bed Series	Leda Myalis bed	
	Forest bed	
	Weybourne Crag	

J. H. Blake, On the age of the Mammalian rootlet bed at Kessingland, shows the Forest bed to be pre-glacial, not inter-glacial. *Geol. Mag.* iv. 1877. Blake calls the Forest bed 'rootlet-bed.'

J. H. Blake, *Address, Anniversary Meeting Norwich Geol. Soc., Proc. Norwich Geol. Soc.* vol. i. p. 94, 1880 (same subject).

The Testimony of the Rocks in Norfolk. Lecture by F. W. Harmer, 1877.

He shows that at (1) Happisburgh, there is stratified sand and brick-earth, made by water. (2) At Cromer there is unstratified chalky boulder clay. (3) At midway between these points there are masses of (2) imbedded in (1). Explanation: Cromer till (2) is a glacial terminal moraine;

midway we have masses dropped by icebergs. At Happisburgh is a marine deposit.

S. V. Wood, Junr., and F. W. Harmer, *An Outline of the Geology of the Upper Tertiaries of East Anglia.*

This work contains a map and sections with numerous sub-divisions of the gravels. The depth of the 'Coralline Crag of Suffolk' sea was probably less than 300 feet. On top of the Forest bed come the 'lower glacial series,' consisting of, at the bottom, deep orange sands with pebbles, and with marine shells, which 'indicate the first setting in of the great Glacial subsidence.' The till is 'merely the deeper water deposit of this early glacial estuary.' 'The pebbly sands are interbedded with the till.' The 'contorted drift' of Sir Charles Lyell, which overlies the last, but is still lower glacial, is evidence of the grounding of icebergs. South of Norwich the deposit becomes very intermittent, and often very thin. The 'middle glacial' is principally composed of sand. It is fossiliferous at Yarmouth. On top of this is the great chalky clay (upper glacial). It is fossiliferous at Bridlington Bay. The 'plateau gravel' is composed almost entirely of flint. Marine fossiliferous gravels of post-glacial age are also described.

S. V. Wood, Junr., The Newer Pleiocene Period in England. *Quart. Jour. Geol. Soc.*, xxxvi. 457 and xxxviii. 692, 1880, 1882. He begins by saying, 'The movements by which the conditions of sea and land have changed in England from the time when the Red Crag began to form appear to me to have been *so continuous* that the formations from this point onwards can be studied with advantage only as one geological group; and as all these have accumulated during *one great movement of depression and re-elevation*, the Newer Pleiocene Period seems to me to be the most suitable term, &c.' He thinks that there was a glacier in Norfolk and Suffolk which reached the sea, and which made a 'submarine extrusion of moraine.' 'The ice which had issued through the Humber to form the till retreated to the top of the chalk wold.' Bergs broke off from this. The great contortions in the drift are due to large introduced masses. 'So far as these masses are found in North Norfolk, so far only, whether in the cliff section or inland, do the great contortions extend; for beyond this area contortions are rare, and of trifling extent, and are due to other causes.'

He thinks that the 'Basement clay of Holderness' was the actual moraine of land-ice sliding off the Yorkshire and Lincolnshire wolds (p. 668). The gravel of the Thames Valley is no more connected with the Thames than with the Severn, being due to a marine submergence. On the south side of the Thames it terminates at an elevation of 175± feet. He thinks (p. 679) that there was a glacier in the Valley of the Lea, and that 'the ice has laid its moraine of chalky clay on the islands on either side of the channel.' He gives a map (Plate xxvi. fig. 4) showing the extent of land-ice in England, and making the ice-sheet come down to the Wash. He gives also (p. 718, &c.) a number of examples of 'atmospheric drift' in the Isle of Wight, &c., which are interesting and should be quoted. This is due to the freezing and thawing of the soil. 'Landwash' is the same. Bones occur in it. He thinks the glacial epoch due to a variation in the *heat of the sun.*

H. B. Woodward, Geology of the Country around Norwich. *Memoirs Geological Survey,* 1881. 'In many places (p. 104) there is considerable difficulty in drawing a definite line between the glacial sands and the Norwich Crag.' The chalk is (p. 134) often disturbed, the flint layers being broken up, and sand and stones introduced, the broken chalk being due, he thinks, 'to the direct influence of land-ice.' Mammalian remains occur in this disturbed chalk in some places (p. 13). [Evidence *against* the glacial theory, I think.] Rev. O. Fisher (*Geol. Mag.* v. 551) is right in thinking the disturbed chalk to be 'disintegrated *in situ* by the percolation of atmospheric water.' A list of papers on the Geology of Norfolk is appended.

H. B. Woodward, *Geology of the Country around*

Fakenham, Wells and Holt, 1884. He says: 'As to Wood and Harmer's division into:—

4. Plateau gravel	Upper glacial
3. Chalky or upper boulder clay	
2. Sand and gravel	Middle glacial
1. Lower boulder clay	Lower glacial

I have been at a loss to find the persistence of any of the above four divisions' (p. 16). Beds have 'frequent and often very abrupt changes in lithological character' (p. 15). In many places the lower and upper boulder clay is identical. Sometimes contorted drift is on top of the chalky boulder clay. *Contorted drift passes into the great chalky boulder clay* (p. 19). In the drift foreign boulders are extremely scarce.

Whitaker, *Geology of Country around Ipswich, &c.*, 1885. Literature at the end.

A. J. Jukes-Brown, *Geology of Cambridge.*

J. Prestwich, Bed of Angular Drift on Lower Chalk between Upton and Chilton. *Quart. Journ. Geol. Soc.*, 1882, p. 128.

Describes landwash as due entirely to atmospheric action. It contains bones, and is of purely local origin. 'Atmospheric drift.'

H. Walker, *The Glacial Drifts of Muswell Hill and Finchley*, London, 1874.

For other papers see S. V. Wood, Junr., *Quart. Journ. Geol. Soc.* xxiii. 394, xxiv. 146, xxiv. 464, xxvi. 90; *Geol. Mag.* vii. 17 and 61.

In these the author agrees with Sir A. Geikie (*Trans. Geol. Soc. Glasgow*, vol. i. pt. 2) that the London gravel was made 'when the country was submerged beneath an icy sea.' Boulders of granite, limestone, &c., occur in the Finchley railway cuttings, also 'second-hand fossils.' H. Walker 'On the Glacial Drifts of North London' (*Proc. Geol. Assoc.* vol. ii. No. 7) describes fresh cuttings at the Finchley and Hendon Stations of the Great Northern Railway to Edgware, six miles north of London.

A. J. Jukes-Brown, On the Evidence for Interglacial Erosion in Norfolk. *Proc. Norwich Geol. Soc.* p. 171. Shows there is no such evidence; that Wood is mistaken, and that there is no unconformity at Cromer between the 'middle glacial beds' and contorted drift.'

Lincolnshire

A. J. Jukes-Brown, On the Southerly Extension of the Hessle Boulder Clay in Lincolnshire. *Quart. Journ. Geol. Soc.*, 1879, p. 397.

Hessle boulder clay makes a curious ridge [1] from Stickney through Sibsey, leaving the edge of the chalk wolds. Burgh stands on a mound of sand and gravel, surrounded by clay (*Quart. Journ. Geol. Soc.* xxiv. 184), which is chalky. At Firsby the Hessle clay is full of chalk pebbles, shown in a railway cutting. A mound of sand is banked against Kimmeridge clay east of Toynton, an eminence of Marden Hill north-west of East Keal. South of Laythorpe the country is hillocky. At Sibsey the boulder clay is a long island rising out of flat silt (Skertchley, *Geol. of Fenland*). Hessle clay is younger than chalky clay and was made in milder times. Hessle clay is made out of purple clay, and is *due to coast ice.* Cromer till is overlaid and underlaid by marine beds. Hessle clay is banked against the wolds and thrust into their valleys. S. V. Wood thought Hessle clay post-glacial, not Jukes-Brown. At Louth the chalky clay comes in from the west and touches the Hessle clay, fringing the wolds on the east.

A. J. Jukes-Brown, The Boulder Clays of Lincolnshire, *Quart. Journ. Geol. Soc.*, 1885, 114.

These are of two distinct types, gray chalky clay and brown (purple and Hessle) clays. Distinct geographically and lithologically.

1. *Chalky clay* (red on my Index Map) is in the south-west (Ponton and Corby) light gray or gray blue; beneath the Fens and northward it is deep blue or blue gray; and

---

[1 This is a shoal or bar.]

east, near the Wolds, it is almost white with chalk. It spreads over the Midlands and East Anglia. There is none on the high ground north of Lincoln, but it is found on the high ground from Somerby to Kelby. A tongue extends across the Wolds from Hainton and South Willingham to north-west of Louth. Near Kelstern it is at 400 feet elevation, and near Gayton it is banked against the chalk. Elsewhere it does not appear on the chalk wolds, but it is seen on the high ground at Grantham, Fulletby, and Scramblesby.

2. *Brown boulder clay* (Hessle) follows the Great Northern Railway from Firsby northward. At Alford it is 60 feet deep. It often overrides the chalk cliff, ascending to 300 feet. North of Louth it smothers the chalk cliff; the boundary was defined sharply by Jukes-Brown. The edge passes into 86 feet, between Wyham and Hawerby, and then rises to 382 feet. It occupies the valley running north from Wold Newton to Ravendale, and extends from Hessle to Ferriby. *Near Welton,* three miles west of Louth, are good exposures of Hessle clay, banked against the chalky boulder clay. [Does not the brown clay pass into chalky clay ? [1]

Hessle clay is the weathered purple clay. Chalky clay is the same as the Holderness basement clay.]

Nottingham to Lincoln

[There is a good exposure of horizontal trias east of

---

[1] It appears that -1. The Hessle clay is due to a marginal lake. 2. When this marginal lake burst westward through various channels in the chalk wolds, it made an angular torrential flinty gravel; the unfossiliferous 'Boulder Gravel' or 'Cannonshot Gravels' of Cromer and Norwich (see *Memoirs*). 3. Debacles thus flowing into the lower ground on and west of the chalk wolds, some formed a more inland and second series of lakes, which contained a mud filled with chalk débris, since the water came across the chalk; and this is the 'great chalky boulder clay. 4. This lake in turn filled up and overflowed west and south past Leicester and Rugby, &c., along the triassic country, making flinty and chalky gravels, the northern drift of the midland and southern counties which is torrential. 5. Rivers from glaciers at York and in Cheshire joined the flinty streams.

Nottingham. A broad, low, alluvial plain continues all along the River Trent from Derby and Leicester to the mouth of the Humber. (*See* Map VI. p. 167.)

The valley is some two miles broad, and is bordered by low triassic hills. At Newark and beyond, the plain appears almost limitless, as seen from the railway train. So, too, at Swinderby, &c. Exposures of gravel occur before reaching Lincoln. It looks like the New Jersey gravel. The drift is said to be 300 feet deep in places.]

Ely

[I walk one mile north to Roswell Pit, where there is a fine exposure of Kimmeridge clay overlaid by chalky boulder clay. The Kimmeridge clay (jurassic) is like a soft shale, but is mud-coloured; it contains hard lenticular masses of argillaceous limestone (septaria or cement-stone), and is fossiliferous. Over it is a marine boulder clay, with many chalk pebbles and flints, often in wavelike curves.

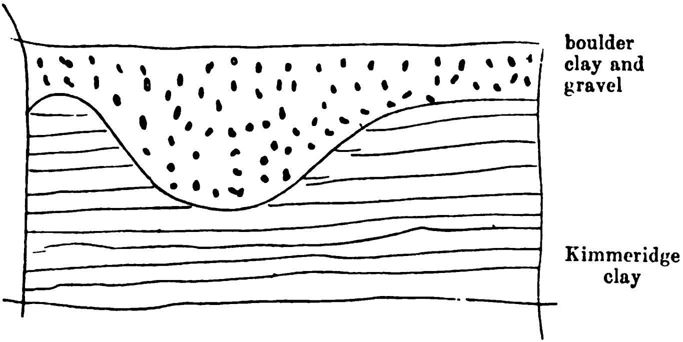


FIG. 47.—Roswell Clay Pit, near Ely.

A supposed huge boulder, 400 yards long, of cretaceous strata lies in the boulder clay here.] (See *Proc. Geol. Assoc.*, vol. viii., No. 3, p. 133, Geology of District visited during Whitsuntide Excursion. Whitaker.)[1]

---

[1] See also *Cambridgeshire Geology*, Bonney, 1875; *Geology of the Fenland*, Skertchley; *Memoir Geological Survey*, 1877, pp. 236 341.

Ely to Cromer

[There is a good view of Roswell Pit from the railway one mile beyond Ely. The flat Fenland, drained by ditches, extends to Brandon. Beyond here are hills thickly covered with flints, apparently due, as is shown by cuttings, to the decomposition of the underlying flint-bearing chalk. Here, then, is the source of much of the flint in the gravels of East England, the flints being already loose for floods to carry south-westward. Exposures of chalk and the overlying decomposed stuff full of flints occur just north of Thetford. There appears to be little or no drift here, but farther west there is much flint gravel.

At Wymondham is a fine exposure, 50 feet deep, of red gravel, with sandy layers. The gravel is on top, and the stratified red sand (pre-glacial?) is below.

At Norwich, near the station, is a cutting and fine exposure of yellow stratified gravel, often contorted, and enclosing layers of false-bedded sand, much resembling New Jersey yellow gravel. Torrential action. It is marked 'river gravel' on the map of the *Geological Survey* (No. lxvi., N.E.), but is very similar to the red sand, gravel, and clay on the higher ground, called 'Norwich crag.' (Pre-glacial.)

It is, perhaps, the 'Norwich crag' restratified. 'Norwich crag' looks like the New Jersey false-bedded red or yellow sand below the Glassborough gravel, being sand, some brick-clay, and much pebbly gravel. No boulder clay is seen about here. This Norwich Crag, also called Weybourne Sands (Lyell) and Weybourne Crag (Reid) underlies at Cromer the 'Forest bed,' just as the New Jersey red sand underlies the Fishhouse Unio clay, which latter is, I believe, coeval with the Cromer Forest bed. The whole is in the Newer Pleiocene (v. *Geol. Survey Memoir*, *Geology of Cromer*, Reid, and *Geology of Norwich*, Woodward.) In the Forest bed at Ostend (between Happisburgh and Bacton), among other fresh-water fossils, Mr. Green found Unio or

Anodon, bones of mammalia, lignite, trunks, &c., a fauna and flora much like that at Fishhouse, New Jersey (v. Reid's *Geology of Cromer*, 1882, p. 41).]

Cromer

[I examined the cliffs from Sidestrand to Runton, six miles in length, but found no till and no evidence whatever of glaciation. There is a continuous succession of stratified, water-made deposits from the Forest bed series, continuously upward to the top of the Glacial series.

Over the Forest bed is a sandy deposit, rarely fossiliferous (the Leda Myalis Bed), forming passage beds upwards into the so-called boulder clay. The latter, however, is clearly stratified, consisting of alternations of sand, clay, and gravel, often highly contorted. It contains rounded pebbles mostly of chalk and flints, among which are unworn flints, just as they occur in the chalk, with huge masses of decomposed chalk, the latter being not in boulders but in *cakes*, as if a layer had been bodily raised; such cakes are sharp at the ends.

These chalk cakes have been raised a few yards from their bed just below, and left suspended in the boulder clay. Not by glacial action, but by torrential marine action as the coast was being raised. The contortions slope *from* the sea, i.e. to the south, as if made by the sea in its retreat. I found no till here. The contorted drift is in great part sand, the contortions sometimes making the strata vertical. Its pebbles are either well-rounded stones, or else flints lifted up from the underlying chalk. There has been one gradual submergence, making all the beds continuous from the bottom of the Forest bed to the top of the contorted drift,' then a gradual elevation, making the overlying sand and gravel, and contorting all the beds as the waves broke on the beach while being elevated. No glacial or interglacial periods could be distinguished. Much rubbish has been written about these 'Cromer beds.' At Cromer lighthouse the sand and gravel on *top* of the contorted drift seem identical with that which elsewhere is *below*, and of Pleiocene age. Rounded boulders and pebbles of crystalline (Scandinavian ?) rocks occur on the beach. Many roots and stems are in the Forest bed, which is a dark compact fresh-water (?) clay identical with that at Fishhouse, New Jersey. It lies on rotten, clayey, white chalk. The contorted drift is like the contortions in the Philadelphia gravel and brick-clay, but on a larger scale. Much yellow sand is in the contorted drift. There are fine exposures just west of Cromer of contorted drift on end. Large chalk cakes (they should not be called boulders) occur at Runton (vide diagram at the end of Reid's *Geology of Cromer*). These cakes are sometimes partly tilted up.

I believe that the large cakes of chalk were raised much in the same way that cakes of ice are raised one on top of another by rivers—namely, by the buoyancy of the water combined with pushing up an inclined plane by the force of the current. The raising of these large soft cakes must have been very gradual. First one end was raised, and the boulder clay was jammed into the crack by the same wave. Then more and more boulder clay was forced in, the cake itself being now and then lifted up. The boulder clay would act like wedges, driven in farther and farther by successive waves, until the cake would be finally raised.

Another hypothesis is that the upper layers of the soft chalk occasionally froze in a large cake. This being light and yet solid was readily raised to a higher level, and left in the clay which was being contorted by the waves. Perhaps the contortions in the clay are due to irregular freezings and thawings combined with wave action. In favour of the freezing theory is the fact that just west of Cromer is a long cake of Forest bed clay, some 30 feet long by 3 feet thick, which has also been lifted and tilted, and left slightly bent in the contorted drift. This soft cake shows that the chalk was also soft and clayey when raised, and thus readily frozen into an ice-cake.

An 'ice-foot' (eisfod) is probably the true explanation.

Dr. Kane (*Arctic Exploration*, vol. i. p. 175), says, 'In this one northern harbour, an icefoot is a perennial growth, clinging to the bold faces of the cliffs,' &c. (vide Kinahan, *Journal Geological Society Ireland*, i. p. 198. 1866–7.]

Unlike stones dropped from an iceberg, these large cakes lie in a more or less horizontal position. Icebergs would have disturbed them. I have seen a layer of gneiss at Philadelphia, with gravel forced between it and the solid rock.

Farther south on the Cromer coast the beds are not so contorted, and large cakes of chalk are no longer seen in them. The whole series of sands and clays are *regularly* stratified, though not more evidently stratified than at Cromer. In the sand of the boulder clay there is false-bedding due to retreating tides, perhaps.

I am astonished at the many statements and numerous papers concerning the 'Cromer till,' which has no resemblance to till at all. All theories of interglacial periods founded on these beds are valueless.

The points determined then are:—

1. There is no till at Cromer.

2. The raised chalk cakes are not boulders.

3. All the beds are successive, conformable, and do not indicate changes of climate.

4. The minor beds are local, and do not deserve names.

5. There has been one gradual depression succeeded by a gradual elevation.

6. There is no evidence of glaciation.

7. The contortions were probably made at the time of the elevation of the coast, the chalk cakes perhaps at the same time being raised. The contortions are due to the larger cakes, being only seen where these large transported masses occur, the latter sinking into the clay and contorting it.]

8. The forest bed merges into glacial beds (vide Reid's *Geology of Cromer*, p. 48, and Woodward's *Geology of Norwich*, p. 104).

See also an excellent paper by T. M. Reade, O Chalk Masses in the Contorted Drift of Cromer. (*Jour. Geol. Soc.*, 1882, p. 222. I quite agree with He has full literature.[1]

Rhomben porphyr *from near Christiania* has been in the Cromer drift near East Runton (*Geol.* Dec. III. 3, vol. iv. p. 331.

On the origin of the Cromer clay, see remar Geikie's '*Great Ice Age.*'

Hunstanton (*Norfolk*)

[Just north of Wolverton are good exposures and cliffs of soft yellow carstone (Neocomian), showing bedding.

I visited the so-called 'Esker,' in the park near stanton (Whitaker, Geology of District visited d Whitsuntide excursion, 1883. *Proceedings Geological ciation*, viii. 133). I saw in an open field a long l gravel resembling a kame in its narrrow ridge-like but not resembling one in that the characteristic knol kettle-holes were absent. With the guidance of the k I traced this hill as far again through the woods a marked by Mr. Whitaker. It turned at right-angle continued as a narrow gravelly ridge in an east an direction for one third of a mile. An old battlen square tower stands on part of this ridge, which is steeper on the northern than on the southern slo sand-pit at the south end of the ridge showed it to c at least in its upper part, of waterworn coarse grav sand. This last looked like sea-sand, not kam Contortions with a little clay in them were seen i parts of this cutting. I have never seen such cont in kames, although they are common in marine drif

Finally in the sand I found many fragments of shells. Shells never occur in kames;

---

[1] *Nature*, September 1886, says 'that Spitzbergen this year rounded by an *ice-belt* from five to eight miles broad.'

I conclude, therefore, that since:—

(1) This has not the contour of a kame;

(2) It shows contortions not seen in kames;

(3) It contains marine shells;

this is not a kame, but is a portion of an old sea-beach.

It is close to the sea, only 50 feet above it, and bends in an arch quite unlike a kame, but just as a beach might, keeping parallel to the present sea-beach.

One part is parallel to the Wash, another part to the sea, and it stands just on the point between the two. Possibly it was caused by the two currents, one of the Wash, the other of the open sea. It is clearly marine, like the gravels of the neighbourhood. Is it a dune? Or a bar? Or a bank?]

9. THE DEPOSITS OF SOUTH ENGLAND

Hemel Hempstead

[I examine the region about King's Langley, Watford, &c. (See Map VI., p. 167).

It is a chalk region with outliers of tertiary conglomerate (Bagshot). Eocene. This consists of flint pebbles cemented by silica. It is washed and locally remade into gravels, composed altogether of flint. A few triassic quartz pebbles also occur.

At Leavesden, one mile south of Abbot's Langley, in a depression or valley at the side of the Valley of the Colne, is a deposit of red gravel, made mainly of local Eocene beds, but containing waterworn boulders of felsitic ash, quartzite, &c. It is a red gravel, like that at Philadelphia, and has a wave structure due to 'warp.'

Red sand occurs in it; also large angular and rotten fragments of chalk. The northern pebbles are sometimes nine inches long. It is a fresh-water torrential gravel, as at Nicetown and Fairmount, Philadelphia. We go down into the Valley of the Colne and find 'boulder clays' and gravel; the gravel at this lower level is identical with that above. It is a red gravel with red sand and with clay above, exactly as at Philadelphia. There is clay also in streaks in this deposit.

No glacial pebbles are seen. No palæolithic implements ever occur in this gravel; but they do in the river gravels made out of it. This gravel is distinguished from that at high levels (reconstructed or decomposed Eocene) by having many northern pebbles (millstone grit, triassic pebbles, &c.). The first gravel corresponds to the Glassborough gravel; this 'northern drift gravel' is the 'Philadelphia red gravel,' and the river gravel with palæoliths is the 'Trenton gravel.' We go to a brickyard at Brickett Wood; marked 'boulder clay' on the Ordnance Map.

Here is a deposit 20 feet deep of tough pure clay, red brown streaked with gray blue, and containing many small fragments of chalk, also flints, and some occasional foreign pebbles. It is precisely intermediate in character between the Hessle clay and the great chalky boulder clay. Dr. Evans calls it the chalky boulder clay. It is clearly both. It makes a ridge in the valley and is worked for bricks. Gravel lies on the top of it.

The gravel contains streaks of this clay. It is the same clay as at Driffield. This is on the St. Albans branch railway.

The *ridge* of clay is due to its having resisted erosion more than the gravels and chalk on either side of it. It is not very chalky here, and I should not call it a chalky boulder clay. It is due to fresh water dammed up. More chalk is found in it farther east. Scratched flints are also said to occur. It is very tough. This is five miles south of St. Albans. It is the most southern and western extension of the chalky boulder clay. Higher land lies to the west and south-west.]

Elephant remains were found under this clay, thus indicating fresh-water conditions. See Hughes, 'The two

Plains of Hertfordshire,' *Quart. Journ. Geol. Soc.*, 1868, p. 283. See Whitaker, *Geol. Memoir*, The Geology of Hertfordshire, of Middlesex, Buckinghamshire, Berkshire, and Surrey, 1864, p. 63;[1] and Prestwich (*The Geologist*, vol. i. 1858, p. 241), who describes this locality as follows: 'At Brickett Wood, on the railway from Watford to St. Albans, is a section 20 feet to 30 feet deep in boulder clay. Gravel occurs above and below it. The lower sandy gravel, made mainly of subangular flints with some quartz and other pebbles, is clean and washed. The upper gravel is similar, but less sandy, and is darker.' In the lower gravel Mr. Prestwich found pieces of the teeth and tusk of an elephant. The lower gravel rests upon an irregular surface of chalk.

Boulder clay is also found on Finchley Hill (*Quart. Jour. Geol. Soc.* xii. p. 133, footnote).

[From Brickett Wood a long valley runs to the north-east toward the low flat ground of the fenland. It is not improbable that in preglacial times this country drained northwards. The Norfolk coast has been deeply eroded in human times, great changes having occurred since the palæolithic period, as Dr. Evans and others have shown. It is evident to me that the ancient Humber mouth was dammed up by Scandinavian ice, and that the chalky clay was made in a marginal lake. The gravel is the fluviatile portion of the same lake. Here I find gravel near the clay to have streaks of clay, while at a higher level at Leavesden it is nearly free from clay, and is sandy. There is thus a

---

[1] Also Whitaker's 'Guide to the Geology of London,' *Geol. Survey Memoir*, 1875, p. 54. This ('boulder clay') 'upper glacial' or 'great chalky boulder clay' is full of stones from the north (lias, Oxford clay, greenstones, granite, sandstones, &c.). These were 'dropped from melting icebergs which floated south from the ice-capped northern country.' No fossils occur in the boulder clay except derived ones; and thus it has been questioned that it was deposited in the sea. The tract north-east of Watford is 'our most westerly patch.' Its most southerly point is at Finchley, where it ends on the northern slope of the ridge that bounds the valley of the Thames.

passage from chalky boulder clay into northern drift gr as we get to the edges of the lake.]

Hughes, The two Plains of Hertfordshire and t Gravels. *Quart. Jour. Geol. Soc.*, 1868, p. 283. Thi the 'gravels of the higher plains must be a marine dep and that the gravels of the lower plain are due also to ma action' [although no shells or other marine signs app and on the other hand, in these very gravels mamma remains (horse, ox, reindeer, mammoth, and rhinoc occur. The pebbles of this gravel are all local, bein rolled flint and jasper.]

S. V. Wood, Junr., On the Pebble Beds of Middl Essex, and Herts, *Quart. Jour. Geol. Soc.*, 1868, p. Thinks that much of the gravel may be of Eocene age. all events, it is redistributed Bagshot. Hughes' 'grav the lower plain' passes beneath the chalky boulder clay

Devon

Devon was supposed to be both *glaciated* and *merged*.

1. The Boulder Committee (*Brit. Assoc. Rep.*, 1 p. 110) pointed out large boulders of felsitic rock so south-west of Torrington (previously noticed in a geolo sketch in White's Dictionary—Devonshire) supposed t ice-borne. But these are probably the outcrop of a subjacent dyke which runs north and south as suggeste Mr. Ussher. (On the Deposits of Petrockstow in D Ussher. *Trans. Devonshire Assoc. Adv. Sc. Lit. and* 1879.)

2. Mr. Maw (*Quart. Journ. Geol. Soc.*, 1864, p. described a gravel bed near Petrockstow which he sup had a Dartmoor origin, and was due to a submergen glacial times. But Ussher (*loc. cit.*) has shown that and other Devonshire plains are preglacial and are nants of an ancient or tertiary deposit made out o cretaceous beds which formerly extended over a large of the North Devon palæozoic area.

W. Pengelly, Notes on Boulders and Scratched Stones in South Devon. *Trans. Devonshire Assoc. Adv. Science*, 1875.

W. Pengelly, Granite Boulders on the Shore of Barnstaple, North Devon. *Trans. Devonshire Assoc. Adv. Science*, 1873.

T. Codrington, On the Superficial Deposits of the South of Hampshire and the Isle of Wight. *Quart. Jour. Geol. Soc.*, 1870, p. 528.

The highest gravels at 420 feet are of local character; they have no marine fossils and no indications of glacial conditions. They are due to an ancient river flowing at a higher level before denudation had formed the present features, and when the Isle of Wight was united to the mainland. The marine gravels with shells occur up to 100 feet, but this elevation may have occurred since man's appearance, as flint implements have been found in them.

On the Isle of Wight gravels at 300 feet are due to old rivers, and mammalian bones occur in them. Boulders of granite, greenstone, &c. (from France) occur in gravel near the level of the sea, and marine beds of the glacial period, when icebergs distributed boulders, do not rise above 100 feet ±. There was a glacial submergence of 100 feet.

Whitaker describes gravels between Canterbury and Herne Bay as indicative of a large ancient river. The high-level ancient river gravels have often angular and unrolled flints, and Whitaker remarks that angular gravel is rare in true marine gravel.

10. *WALES*

References

D. Mackintosh, Erratics in Llanarmon Parish, Denbighshire, &c. *Quart. Jour. Geol. Soc.*, 1874, p. 711.

Valuable paper. The boundary line (moraine) between the Northern and the Welsh drifts is given. A great accumulation of boulders at the edge of the Welsh glaciated area about Llanarmon is described. Striæ are given near Holywell, Caergwrle. A great boulder at Cefn and another at Eryrys are described. Boulders were transported uphill. Localities of boulder accumulations are given.

D. Mackintosh, High Level Drifts in North Wales. *Quart. Jour. Geol. Soc.*, 1882, p. 184. Describes a 'drift zone' (moraine) between Minera and Llangollen Vale. It rises in the form of mounds and hillocks, being 1,000 to 1,300 feet above the sea. Driftless areas in North Wales are described.

D. Mackintosh, *Quart. Jour. Geol. Soc.*, 1874, p. 174, shows that a great ice-sheet which extended on a level between Snowdon and Moelwyn flowed outwards, ignoring local valleys and hills, flowing *from* south-east and south.

A. C. Ramsay, *Quart. Jour. Geol. Soc.*, 1876, p. 116. Good paper describing the local glaciers of North Wales.

A. C. Ramsay, The Geology of North Wales. *Geol. Survey Memoir*, vol. iii. 1881, p. 271, &c. Masses of drift are at Beaumaris, and a moraine-like mass is at Penrhyn Castle.

W. Keeping, Glacial Geology of Central Wales. *Geol. Mag.*, 1882, p. 251.

The drift of Cardiganshire and the neighbouring counties is purely local except on the extreme north and south borders of Cardiganshire.

Striæ, &c., are common.

Nant Neyheran was filled with a glacier.

There is till at Aberystwith.

Roches moutonnées are at the head of the Llyfnant Valley, Claerwm Valley, Machynlleth, Plynlimon, Llyn Fyrddyn Fawr, Lake Glaslyn, Lake Bugeilyn, Cwm Berwyn Farm, &c.

There is a fine mass of till south of Aberystwith, all the rocks being of local origin. Cwm Ceirw drift. Cliff sections of till are opposite Llanrwsted.

Long lines of moraines are on the south sides of Cwm Berwyn, and in Cwm Ystwyth.

Terminal moraines often form the banks of lakes, as Llyn Glaslyn, L. Gwyddir and L. Llygad Rheidol.

Other terminal moraines are below Diffwys and in Blaen-y-Cwm, and Cwm Ysrugth under Craigddw.

Erratics are crowded over the country east of Llanfihangel and Cwm Ystwyth like sheep; but are almost absent about Llynidd Ienam.

Erratics occur as high as 1,200 feet, but are all local, i.e. graywacke and shaly slates (above Cwm Symlog, towards Gogilan).

Erratics are fine about Llyn Eiddwm and L. Berwyn and Nant-y-maen Trigorm. The boulder of conglomerate on Gogerddan Hill comes from Plynlimon Hill.

Boulders from beyond the present drainage area occur only at the extreme north and south.

South of Machynlleth in Llyfnant Valley are blocks of felsite which came from the north (Cader Idris or Aran Range).

This is the *only case* of the invasion of Central Wales by northern ice.

A glacier flowed over the pass south of Machynlleth, and so into the Llyfnant Valley. Blocks occur also in the main valley south of Machynlleth.

At the south end of the county around Cardigan is a clay holding mountain limestone, old red sandstone, felsites, greenstones, &c.

This is due to a large glacier which originated in Caermarthenshire in the hills of South Wales, where it got *palæozoic* pebbles and then streamed westward over the watershed, down Teifi Valley, and to the Irish Sea.

Boulders of these same foreign rocks occur farther north towards Aberystwith up to 700 feet.

On Aberystwith beach are pebbles of agate, chalk flint, granite, greenstone, mountain limestone, &c. &c., which are due to clay in the Irish Sea, such as occurs with the same pebbles in Anglesea and the Lleyn Peninsula.

An *esker*, with morainic contours, occurs near Llanrysted Road Railway Station, where the Ystwyth Valley opens out into the broad plain. It is 120 feet high.

Conclusion. No mer de glace was here. All were local glaciers. No evidence of more than one glacial period was observed.

Chester to Ruabon, Mold, Hope, and Rhyl

[There is much drift about Ruabon. I walk to Mountain Lodge.

Boulders of granite are very abundant all the way from Ruabon to the foot of the mountain.

A large boulder of granite lies on the road-side at Ruabon, and they abound between here and Offa's dyke. They are found abundantly on the road, in the fields, and built into walls.

The granite is either red or white according as the felspar is coloured.

It is very silicious, containing many irregular masses of gray quartz. A black mica occurs in small quantity (Eskdale granite ?). Boulders of limestone also occur, together with sandstones, felsites, &c. Granite boulders are abundant in the hill of drift at Tainant.

All this seems to be the moraine, the most noticeable characteristic of which is the quantity of granite. A great depth of drift is exposed by the cutting of the stream at Tainant. It is heaped up in the low mounds so characteristic of a moraine, and is unstratified and stony. This is (barometer) 600 feet above the station at Ruabon.

Higher up at Mountain Lodge we enter a wild region where the moraine, still filled with boulders of granite, is magnificently exhibited, and as finely as anywhere.

Long ridges of drift covered by heather but uncultivated, run about north and south, parallel with the main movement of the ice, a true lateral moraine. Well worth a visit. It is sprinkled with large boulders. In great part it is quite unstratified, and contains striated pebbles. Sandy portions also occur, as in all moraines. This is 650 feet above the railway at Ruabon.

I return to Ruabon and go to Wrexham, Hope, Mold, Denbigh, St. Asaph, and Rhyl by train.

Low hills of gravelly drift are seen near Gwersyllt, the ridges running about parallel to the railway, north-northwest.

A higher and more moraine-like ridge appears north of here.

West of Cefnybedd Station the isolated mass of Hope Mountain is seen, about one mile and a half distant, and drift hills lap up on it.

Did the ice-sheet go over it? It probably did not.

(See Mackintosh, *Quart. Jour. Geol. Soc.*, 1874, p. 712.)

There is much sandy and gravelly drift about here and Caergwrle and at Hope Junction, but nothing morainic, all lying in very flat lenticular hills. The moraine is still farther west. At Hope the land is perfectly flat.

Drift 30 feet deep is cut through at Padeswood, but the land is flat beyond. There is some drift at Mold, and rock covered by drift occurs a few miles beyond.

We follow up a river bottom. At Rhydymwyn is a flat river bottom, with hills on either side. Above here are deep cuttings through limestone.

Then comes the moraine (?), a great mass of drift in characteristic knobs, lying on limestone on the top of the watershed, and full of limestone boulders. This is one mile below Nannerch.

At this place is more drift overlying the limestone.

About Caerwys is red sand forming hills. This is probably a red sandstone rock.

At Bodfari the red rock is exposed, and just beyond here are cuttings through morainic drift, after which we enter the broad valley deeply filled with drift, in which Denbigh lies.

Going from Denbigh northward we seem to ascend for a while, afterward to descend, but the whole broad plain is comparatively level.

Just north of Trefnant are long cuttings through drift, and there are others south of St. Asaph. An immense and deep mass of drift fills the valley, and the river makes a cutting through it.

At St. Asaph it is seen to be heaped up in hills of moraine-like contour, and is probably the terminal moraine of the ice-sheet, somewhat modified by river action.

It is well shown about St. Asaph. From a point about a mile north of here a flat plain extends to the sea at Rhyl.

The moraine appears to be heaped up just east of Penmaenmawr Station and near Conway, and east and west of Llandudno Junction.

The rocks about Llandudno (limestone) are striated, and roches moutonnées from the sea.]

Welshpool, Newton, and Machynlleth to Barmouth

[At Montgomery is a large mass of till, made of silurian slates, containing many rounded boulders.

There is a good section at Montgomery Station. Beyond here rock outcrops, with till upon it. Farther on is much bare rock. Again a fine moraine, made of typical till, and heaped up into fine hummocks like a great terminal moraine, is encountered before we reach Newtown. We are clearly in the midst of local Welsh glaciation.

Beyond Newtown is a large hillock of till resting upon a glaciated surface of slate. The valleys are deeply filled with drift, and the hills are rounded off in the region of Moat Lane Junction.

Masses of till overlying shale are well exposed just beyond Pontdolgoch. Many large erratics occur in the drift between there and Carno, the till being stony and unstratified, as in the glaciated mountain region of Pennsylvania.

Between Carno and Llanbrynmair we cross high mountains, not much drift being seen on this high ground, but on the west side, at and beyond Llanbrynmair, deep till again appears. At Cemmes Road is till overlying rock. Along the coast is rock until we reach Towyn, where there is drift. Just north of here is a fine moraine, which comes down to the shore and is there exposed.

At Barmouth typical stony till occurs here and there. I go north, viâ Portmadoc, Carnarvon, and Bangor, to Llanfairfechan. There is a magnificent cliff of till, 75 feet high, full of boulders, and freshly exposed in the railway just north of Llanbedr (below Harlech), where rocks appear.

At Minffordd Junction the silurian rocks are penetrated by many veins of quartzite, which means that we are adjacent to an igneous dyke. There is a quarry in greenstone (?) close by.

I begin to think that the formation of quartz veins and silicification is generally due to the siliceous waters, accompanying igneous rocks. The rocks here are highly glaciated and smoothed down, and are surrounded by moors near Criccieth. (Wild moors, beach and rock on sea. A good place to stop.)

Deep till, with many large boulders, covers the land, and makes the moorland extending from Afon Wen to Carnarvon. North of Ynys are peat bogs, and at Brynkir are hills of till, and many large boulders (a huge one at the station) in the till and scattered over the moors.

At Pantglas peat 4 feet deep is cut. The large boulders are apparently mainly carboniferous limestone, and are very common. It is a bleak district, and nearly treeless. Very large hills of coarsely stratified drift, full of large boulders and knob-like in shape, occur near Penygroes (the junction for Nantlle). All this probably belongs to the great ice-sheet, not to the Welsh glaciers.

Beyond Carnarvon, and especially about Menai Bridge, signs of glaciation are not apparent; rock comes to the surface, decomposed on top, and with apparently no drift.

At Bangor some stratified drift is seen on the rock, though the higher rocks appear to be bare and non-glaciated.

A large hill of drift is, however, cut through a few miles beyond Bangor.

Masses of drift are seen all along the coast, banked up against the rock terrace, the drift being filled with boulders brought from the north. The moraine dividing the glaciers of Wales from the northern ice-sheet is farther inland.] See for a list of striæ, &c., an important memoir of the Geological Survey:

'The Geology of the Coasts adjoining Rhyl, Abergele, and Colwyn,' by A. Strahan, 1885 (Expl. of 79 N.W.), which also gives copious literature by W. Whitaker.

He shows that the transport of erratics corresponds with the striæ; that striæ occur only where true boulder clay occurs; that the boulder clay is identical with that of Lancashire and Cheshire, and that the striæ and transportation of erratics are all due to one cause (according to him floating ice, p. 40). Eight cases of glacial striæ in the district are given, some due, in his opinion, to a southward oncoming ice-cap, and others to the Welsh sheet moving northward.[1]

The drift from the north contains broken shell fragments, mostly *Cardium edule*.

Esker-like ridges of sand and gravel are described. The boulder clay usually lies on the sand and sand hills rise through the clay, as though the sand was due to subglacial currents.

---

[1] Or are all from the north? Investigate.

The drift (till) is deep and is exposed about Llandudno.

Craven Arms to Caermarthen

[Going south-west from Craven Arms there is no trace of drift, not even in the valley bottom, or in the streams coming from the mountains. If there was a submergence, how is it that no marine gravels or sands or clays got into this region? If there was a submergence of 1,300 feet, surely the late tertiary strata would be folded and faulted, and would not lie as they do. (See Map VI., p. 167.)

At Llanbister Road I see some local clay and rounded local stones in a valley which has a flat bottom. Mountains rise to the east of us at Dolan. There is no trace of glaciation.

On reaching the Valley of the Ithon, north-east of Llandrindod, a moraine is seen, made of dark till, filled with glaciated erratics. The valley is filled with till. The clay that I saw in the valley at Llanbister Road was then made in a marginal lake probably. Since then we have been going down the valley towards the glacier. Glaciated stones abound at Llandrindod, and the moraine is large, stony, and well heaped up, a quarter of a mile beyond the town. The River Wye comes through a narrow gap into the broad drift-filled valley which we are descending. We leave the moraine for two or three miles, and then enter it again before reaching Builth Road. It is here characteristically heaped up in hummocks of till, full of glaciated stones. How did the glacier come down?[1] Surely not through the narrow gap of the Wye. We cross the Wye and ascend to higher ground, immediately getting into a driftless unglaciated area. There is no drift about Garth or Llangammarch. We descend toward the river, and again get into the track of a glacier. Just before reaching Llanwrtyd till appears in force.

---

[1] It came from Plynlimon.

The valley is covered with stony till. Lateral moraines are well shown as ridges parallel to the sides of the valley; we again rise on to a higher ground.

There is a fine cutting through the terminal moraine just before entering a tunnel. Fresh exposure. Stony till. Stratified sand layers in it are inclined at high angles. The moraine here is banked against a mountain. We go through the tunnel, and are out of this glacier's track. But we soon descend toward the path of another glacier. At Cynghordy, where is a broad valley, there is *fringe drift* making a thin covering on non-glaciated rocks; the valley is flat, a shrunken river meanders in it, and finally we reach the moraine, full of scratched stones, at half a mile north of Llandovery, at the river's confluence with the River Towy. Again we have a marginal lake, blocked up by the Towy glacier. We keep down the Towy, but seem to be away from local glaciers. The valley is full of stratified drift, but I see no lateral moraines.

Have we entered the area of the confluent ice-sheet of the Brecknockshire Beacons? The valleys are drift-filled. As rocks appear at Llandeilofawr, it may not be glaciated; uncertain. Turning west to Caermarthen, the drift-filled valley and rounded hills on either side continue. I see, however, no true till, no hummocks of drift, and no signs of smoothing on the rocks on either side. The gravel in the valley is like the Trenton gravel of the Delaware—gray and sandy, and the terraces are low. At Caermarthen a high terrace rises above the river, much higher than at any point farther up the river, and the town is built upon it.

I go up to the hills back of the terrace and find an abundant deposit of clayey till, filled with transported stones. We are in a glaciated area.]

Caermarthen

[Caermarthen is built upon a terrace of drift, which terrace is seen extending along the edge of a drift-filled valley to the northward. At Caermarthen Junction is deep till, heaped up like a moraine. Perhaps the supposed terrace is really morainic. We turn southward, and go down this valley, following the River Towy, and find that the drift heaps disappear just below Caermarthen Junction, rock appearing on either side of the drift-filled river valley. It looks as if the drift at Caermarthen Junction was the true moraine of a glacial tongue which stopped here. Rocks (new red sandstone?) outcrop on both sides of the river at Ferryside and are not glaciated. Boulder drift is next seen at Llanelly. As non-glaciated rocks appear also, this may be a wash down the valley from the glaciers of the Black Mountains (Fforest Fawr). The coarse boulder drift seen between Llanelly and Gowerton rests on non-glaciated rock, and is at a low level. The deep boulder drift at Cockett and Landore Junction is sometimes heaped up, but appears to be stratified, and is of doubtful origin. As some of it is clayey and the drift is abundant about Landore, it is probably glacial. Heaps of drift occur farther east on soft coal measures, and I see large boulders, one of them apparently scratched, so I believe that we have entered a glaciated district. Drift continues to Neath, where a large open valley leads up to the Brecknockshire Beacons. (I use the London and North-Western Railway's map.) We turn south-east toward Port Talbot, and *apparently* get away from the drift. (Collieries about Aberavon drive for coal under the sea, and are placed on the sea-shore.) (The trees here are all bent inland to the north-east.)

We again reach masses of stratified drift, filling the low ground about Pyle. There is a large quarry of limestone at Bridgend, which limestone is in uniform layers, interbedded with shale (and thus like jurassic limestone), no drift being seen here, or east of here, till we reach a mass of boulder drift, which makes a watershed, and is apparently a moraine, about two miles west of Llantrissant.[1]

---

[1] See paper by J. W. E. David, 'On the Evidence of Glacial Action in South Brecknockshire and East Glamorganshire,' *Quart. Jour. Geol. Soc.*, 1883, p. 39.

More morainic heaps are seen just east of Llantrissant, and we are again, it seems, in the path of a glacier; but we soon apparently re-enter a non-glaciated region. At Cardiff I see no till, only gravel in the lowlands. The soft red poikilitic (?) rocks at Newport do not seem to be glaciated. At low water in the river at Newport I see a *tough clay* (not unlike, perhaps, the Wexford marl or the great chalky boulder clay). Just east of here is jurassic tabular limestone, not glaciated. This continues up the Bristol Channel, and it is clear that this channel had its origin in being a limestone valley. (Was the Irish Channel filled with cretaceous deposits? Answer: Note the Wexford flints. Was the North Sea also filled with chalk? Answer: Note the Durham flints.) There are no glaciated rocks on the Wye about Chepstow, though they often outcrop in crags. There is mud or clay at low water, but this Wye Valley is not drift filled, and on the railway from here across the limestone cliffs to the Severn I see no drift. The river drift of the Severn Valley does not extend over half a mile north-west of the river about here and Lydney.]

The submergence in South Wales was prior to the main glaciation. Chalk flints in South Wales occur up to 400 feet. Chalky gravels *underlie* the till; they occur only in the south and not above 400 feet; there is no trace of them north of the southern outcrop of coal measures. The submergence was up to 400 feet. (Vide J. W. E. David, 'Glacial Action in South Brecknockshire and East Glamorganshire,' *Quart. Jour. Geol. Soc.*, 1883, p. 39.)

[It is the same in Wexford, Ireland. There was a preglacial submergence of 380 feet.]

Glaciation of Wales

[Wales may be divided into three parts, each of which was a distinct glacial centre.

First region.—North Wales. Down as far as the River Dovey. Large glaciers here coalesced to make the ice-sheet which moved eastward from the Snowdonian centre.

This centre was composed of several mountains forming a rim, as Snowdon, Carnedd Dafydd, Moel Siabod, and Moelwyn—i.e. the mountains about the Pass of Llanberis. This basin was full. It was highest and the ice thickest on the western side; why, then, did it not flow out over Anglesea?

Striæ and erratics show that it did not, also the terminal moraine. Answer: Because a high barrier prevented it from doing so, and forced it to discharge to the east, which it did in a huge stream. This barrier was the northern ice-sheet which filled up the Irish Channel.

Second region.—No boulders from this area got south of Plynlimon into the middle area of Cardiganshire. In fact, only for a few miles south of the River Dovey, about Machynlleth, do any erratics occur.

The mountains of Cardiganshire supported purely local glaciers.

The third region is that of the Brecknockshire Beacons. This also was purely local. The ice ran north, south, east, and west.

Another large stream went west by north, and encroached a few miles upon Cardiganshire.]

11. *ISLE OF MAN*

Excursion with the British Association, September 1887

[There is a granite mountain near Foxdale, described by J. G. Cumming as a 'granitic bubble about a mile long by three-quarters of a mile wide, and about 757 feet above the sea-level.'

South Barrule (1,585 feet) is south-west of this granite mountain and 800 feet above it.

Granite boulders have been driven south-west from the granite bogs, and elevated to points 800 feet above their source.

Granite boulders occur along the ridge which unites Irey-na-Shaa (1,445 feet) with South Barrule (1,585 feet). Cummings 'picked up a few of them, the size of a good cannon ball, quite on the top of Irey-na-Shaa, 700 feet above the top of the granitic boss. One lies within 60 feet of the top of South Barrule, on the western side of the mountain, being not less than two tons in weight.' The summit of South Barrule is in a direct line between this boulder and the granitic boss whence it came, and the difference of height is 768 feet. The distance is a mile and a half from South Barrule to the boss. A number of boulders were found here. As there is a depression between the granitic boss and the mountain across which the boulder must have been transported, there is a total rise of 799 feet. (If we reckon 768 feet to a mile and a half, it is a rise of 512 feet to the mile—a very interesting point. This is a rise of rather less than 9° (?). In the Grindelwald glacier it was not over 5°.) Cummings thinks this is 'evidence of some great diluvial action,' and 'great waves of translation.' It is really an admirable example of glacial translation and elevation.[1]

The boulder clay to the leeward of any particular rock has the predominant colour and mineral contents of that rock; to the leeward of the old red sandstone it has a reddish tinge, of the limestone and shales a dark dingy blue. There were no local glaciers in the Isle of Man. Long ellipsoidal hillocks, whose major axis is in the direction of the general drifting current (as shown by the subjacent scratched rocks), occur in the south of the island. The eastern side of the island is the '*stoss seite*.' It is held to be due to the 'extraordinary action of great waves acting upon masses of ice.'

---

[1] For other cases of glacial elevation, see Goodchild (*Quart. Jour. Geol. Soc.*), who shows that some erratics have been raised from 700 to 1,350 feet, while others have been raised 1,000 feet. Professor Jas. Geikie quotes other cases given by Tornebohm, where blocks occur at 4,500 feet, whose locality is only 1,800 feet (*Trans. Geol. Soc.*, Glasgow, iv. p. 385).

I drove to Snaefell, the highest mountain of the island, and climbed up it. It has clearly been buried under the Irish Sea glacier, for I find erratics, striated boulders, and striated rock surfaces almost up to the summit. Boulders of actinolitic and hornblendic rock occur on the side of the mountain; striated fragments of shale were seen; and the quartz veins which project from the hydromica shales were found upon close inspection with favourable light to show faint traces of striation from the north and north-east. The whole shape of the mountain is that of a 'roche moutonnée.']

12

ADDITIONAL REFERENCES TO THE LITERATURE OF GLACIAL GEOLOGY, WITH ABSTRACTS

There was a submergence in South Wales prior to glaciation.

Chalk flints occur in South Wales up to 400 feet. Chalky gravels underlie the till. Chalk gravels occur in the south, and only up to 400 feet; there is no trace of them north of the southern outcrop of coal measures. The submergence was up to 400 feet.

J. W E. David, Glacial Action in South Brecknockshire and East Glamorganshire. (*Quart. Jour. Geol. Soc.*, 1883, p. 39.)

[It is the same in Wexford; i.e. a pre-glacial submergence of 380 feet.

The very slight erosive power of the extreme edge of ice[1] is illustrated.

(*a*) By superposition of the moraine on pre-glacial gravel as in New Jersey.

(*b*) By the superposition of till on chalky gravel as in South Wales. (See the above reference.)]

(*c*) By superposition of the moraine on pleiocene gravel in North Italy (Godwin Austen, Tertiary Formations at the South Base of the Alps, North Italy. *Quart. Jour. Geol. Soc.*, 1884, p. 855). A massive moraine there rests upon soft pleiocene sandy loam.

---

[1] J. Geikie, Preservation of Deposits of Incoherent Materials under Till or Boulder Clay. *Geol. Mag.*, 1878, v. 1.

(*d*) Superposition of the moraine on the pre-glacial shell bed at Flamborough Head (p. 44).

H. **Miller** (Tyndale Escarpments, *Nat. Hist. Trans. North Durham and Newcastle-on-Tyne*, 1880, vol. vii.) shows clearly that at high elevations glaciers did not erode. He rightly differs from J. Geikie (*Great Ice Age*, 2nd ed., p. 286), and Green (*Geology*, 1st ed., p. 446), who think that glaciers have planed away escarpments. They erode only at low levels.

Bonney (Notes on Glaciers. *Geol. Mag.*, 1876, p. 198) says a glacier can pass over débris as a river does over a gravelly bed.

[I saw the Grindelwald glacier go over and grind down its own moraine.]

Lamplugh (*Geol. Mag.*, April 1881, viii.) describes a shell bed under glacial till (the moraine) at Speeton.

Evidence in Scotland of two glacial epochs

Dr. **Bryce**, in *The Geology of Arran*, 4th ed., 1872, p. 85, describes evidence of two glacial epochs in a section of drift beds made by Dr. Crosskey. Surface soil. Upper drift (stones and sand); clay with shells, 7 feet to 10 feet; lower boulder clay, 12 feet to 20 feet. Rock.

Shells in the drift of Cheshire

These shells are, as Mr. Belt observed, a mixture of northern and southern species, and of deep and shallow water forms. He refers to the opinion of Edward Forbes that the shells in the northern drift do not indicate a sea-bottom or sea-beach, but have been transported from lower levels. Shone states that the upper boulder clay is a tough clay, breaking into columns in dry weather, and containing at Newton 57 mollusca, 2 polyzoa, 26 ostracoda, 2 cirripedia, 2 annelides, 3 echini, 2 sponges, 55 foraminifera. The microzoa were in gasteropods in sand. [This upper boulder clay, elevation 140 feet, is here clearly marine.] The underlying sand examined by him had a few rolled shell fragments. The lower boulder clay with striated boulders of northern origin had no shells. (Section on the Midland Railway between Chester and Mouldsworth.) [The fauna of this upper boulder clay is clearly littoral or sub-littoral. The shells are not *in situ*, but were distributed by ice-rafts. The boulder clay was made in still water.

The Liverpool boulder clay and its mollusca described by Reade, is identical with this. Yet one is called lower, the other upper, boulder clay. Are they not identical? The shells in both are essentially northern and Scandinavian.

The shells in the middle sands, however, are very often of southern origin. The few southern shells in the Liverpool and Newton boulder clays are derived from the older sands. The middle sands I believe to be due to the melting of the ice, and the shells, like those at Moel Tryfaen, Two Rock Mountain, and Macclesfield, to have been brought by the glacier out of the sea. The upper boulder clay of Newton (and the so-called lower boulder clay of Liverpool perhaps) is a marine deposit, made when the ice was retreating and its place taken by the sea, which was then cold. The Montreal deposit corresponds to this, and to a submergence of 200 feet ±. Mr. Shone says boulder clay goes up to 500 and 600 feet, but can it be shown that this is marine boulder clay? See Mr. Shone.

(W. SHONE, On the Glacial Deposit of West Cheshire. *Quart. Jour. Geol. Soc.*, 1878, p. 383.)

Buried valleys denoting former elevation

J. M. READE, Buried Valley of the Mersey. *Proc. Liv. Geol. Soc.*, 1872–73, p. 42.

J. CROLL, On Two River Valleys buried under the Drift (*Trans. Edinb. Geol. Soc.* vol. i. p. 330, and *Geol. Mag.* vol. vii. p. 296), showing Scotland to have been at least 260 feet higher than it is now.

Flamborough Head buried valleys. Pickering Valley and about Scarborough and Whitby. (STRANGWAYS, Scarborough, Dakyns. *Proc. York. Geol. Soc.*) The Danes

Dyke valleys show an elevation of 50 feet±. But a buried valley at Danes Dyke shows the bottom of the filled valley to be no lower than the sea, this being because the sea has cut away the former coast.

Strangways, Geology of the Rocks South of Scarborough. *Memoir*, 95° S.W. and 95° S.E. An old buried valley at Scarborough is 100 feet below sea-level.

There are no buried valleys in the South of England, i.e. no pre-glacial elevation.

The drift at Burdon Main, near Newcastle, as shown by borings for coal, goes down to 138 feet below sea-level.

No submergence in the South of England

1. W. A. E. Ussher, On Terminal Curvature in the South-west Counties. *Quart. Jour. Geol. Soc.*, 1878, p. 49. Answers a paper by Mackintosh (*Quart. Jour. Geol. Soc.* xxiii.), and shows that there was neither glaciation nor submergence in Devonshire. The boulder gravels of the Dart (*Trans. Dev. Assoc.*, 1876, p. 427) and Teign Valleys (*Quart. Jour. Geol. Soc.* xxiii. 418, and *Geol. Mag.* vi. p. 40) are due to ancient larger streams. Raised beaches give a maximum depression of 60 feet. Lithodomus borings at 235 feet are pre-glacial. There was no submergence over 60 feet in Devon, Somerset, or Cornwall. There was a submergence in Norway up to 470 feet, as is shown by marine shells (Kjerulf).

2. S. V. Wood, Junr., The Newer Pleiocene Period in England, *Quart. Jour. Geol. Soc.*, 1880, 457. Gives levels of high-level gravels, which occur in patches in England. The patch at Aldershot at 600 feet, and on the Cotswolds at 760 feet, &c., are regarded as indicating submergence. [Are they not old river-courses ?] 'The level to which gravel rises on the eastern slope of the south extremity of the Pennine is not over 350 feet,' p. 476. Wood explains this, and the absence of drift on the South Pennine Hills, by the denuding action of the ice of the chalky clay. In France gravel occurs up to 130 feet only (Barrow, *Proc.*

Geol. Assoc., 1879, p. 31). Cromer Lighthouse Hill, 247 feet, is one of highest points in Norfolk covered by marine (shell-bearing) gravel. He argues from the supposed submergence of Moel Tryfaen.

Chalky boulder clay on sheet 66 goes up to 90 feet, sheet 48 to 100 feet, sheet 1 to 170 feet; 300 feet on sheet 46, 380 feet on sheet 53, 300 feet on sheet 7 at Finchley. [He is mistaken in thinking that the Californian stuff described by Dr. Crosskey is chalky boulder clay.] Prestwich (*Geologist*, i. p. 241) describes chalky clay at Brickett Wood. Sheet 7 marks it at 256 feet, but this and similar places are due to old rivers. In sheet 46 chalky clay at 482 feet occurs at Southend Steakley.

A seam of sand in the basement clay of the cliff at Dimlington is full of perfect specimens of nucula (an Arctic shell). This fauna is the most Arctic of any known in England. Beds at Moel Tryfaen and Macclesfield contain none of the three Arctic species found at Dimlington, and their fauna is not nearly so Arctic as that of Bridlington. [The above paper is theoretical, misleading and confusing.]

3. W. A. E. Ussher, The Pleistocene History of Cornwall. *Quart. Jour. Geol. Soc.*, 1879, p. 6. The oldest gravels are at 400 feet, are fluviatile, and are patches of age anywhere between the cretaceous and glacial, probably tertiary. Boulder gravels go up to 40 or 50 feet above the sea.

4. A. J. Jukes-Brown, The Boulder Clays of Lincolnshire, *Quart. Jour. Geol. Soc.*, 1885, p. 114, with map. Contradicts S. V. Wood, Junr. Chalky boulder clay goes up to 400 feet on the chalk wolds at Kelstern. The brown clay has stratified sandy beds and marine shells, and is a marine deposit. A submergence (of 600 feet?) ameliorated the climate, and cut off the supply of chalky boulder clay. As the land emerged, the purple clay was made. The Hessle and purple clays are the same.

Made during emergence—

Hessle clay } Newer glacial
Purple clay }

Made during submergence—

Chalky clay } Older glacial
Cromer series }

5. H. B. **Woodward.** Superficial deposits in the neighbourhood of Newton Abbot.

Gravel occurs at 540 feet, but this is older than the denudation of this district. Pre-glacial. Perhaps prepleiocene.

6. W. H. **Penning**, Physical Geology of East Anglia during the Glacial Period. *Quart. Jour. Geol. Soc.*, 1876, p. 190.

One submergence followed by elevation accounts for all the gravels and clays. It was a submergence of not less than 400 or 500 feet. [It looks to me as if East Anglia was submerged to 500 feet, but not the rest of England. At the time of the Cromer Forest bed we had elevation, and England was joined to the Continent. Arctic conditions did not prevail until late in the period of submergence.]

7. Topley and Foster (*Quart. Jour. Geol. Soc.*, xxi. p. 443) describe gravels at 300 feet as made by the River Medway when it flowed at a higher level.

8. The Isle of Portland is 500 feet high, and is quite free from drift, except that at 400 feet is a fresh-water drift containing teeth of *elephas antiquus*, &c., being a local wash. Another local deposit, perhaps pre-glacial, is at 790 feet, near the summit of Blackdown, with pebbles of quartz, flint, chert, jasper, &c. Probably, as Professor Prestwich supposes, these pebbles represent ancient stream-courses along which the water flowed before erosion had cut away the ground. The denudation of the plain of Weymouth, and the deposition of the several drift beds to be found thereon, are more recent than the mammaliferous drift of Portland (J. **Prestwich**, Notes on the Phenomena of the Quaternary Period in the Isle of Portland and around Weymouth. *Quart. Jour. Geol. Soc.*, 1875, p. 29).

The supposed pluvial period

A. Tylor has suggested a pluvial period to which is due the flooded rivers which made the quaternary gravels. He is mistaken in thinking the gravel of the Aire at Bingley to be due to rains, and is also mistaken about the Taff River in South Wales, both of which rivers are filled with glacial stuff. *Quart. Jour. Geol. Soc.*, 1868, p. 455; 1889, p. 57.

Levels of glacial shell beds

R. Richardson, On the Discovery of Arctic Shells at High-levels in Scotland. *Trans. Edin. Geol. Soc.*, vol. iv. pt. ii., p. 179. Gives all the localities of Arctic shell beds. Moel Tryfaen, 1,392 feet. Snowdon, 1,300 feet. Vale Royal, Macclesfield, 1,150 feet. Mottram, near Manchester, 568 feet. Ballyedwarduff, Ireland, 1,300 feet. Scotland:— Chapelhall, near Airdree, 510 feet. Drummore of Clava, Invernesshire, 500 feet. Ardersin, Fort George, 50 feet.[1] The Ord, near Portsoy, Banffshire, 400 feet. Stornoway, Lewis, 350 feet. Loch Lomond, 320 feet. Arran, 320 feet. Auchleuchries, Aberdeenshire, 300 feet. Caithness boulder clay to 200 feet. Gamrie, near Banff, 150 feet. King Edward, near Banff, 150 feet. Campbell Town, Argyll, 130 feet. Elleshill, near Peterhead, 120 feet. Crofhamie, Dumbartonshire, 100 feet. Kilmaurs, near Kilmarnock, 90 feet.

Shells occur in the till of the Orkneys. The shells at Endrick, near Loch Lomond, were (according to Jack) carried up to 320 feet by a glacier which swept them out of a lower inter-glacial or pre-glacial shell bed.

The Caithness boulder clay has the same species of Arctic shells as the high beds.

James Fraser, of Inverness, First Notice of a Post-Tertiary Shell Bed at Clava, in Nairnshire, indicating an

---

[1] The figure preceding '’50 feet' was not legible in Professor Carvill Lewis' note; it is probably 450 feet.—J. F. L.

Arctic climate, and a sea bed at a height of 500 feet. *Edin. Geol. Soc.*, November 1881, p. 136. The highest marine bed in Scotland is at 570 feet. The shells are Arctic in character. No shells are in the boulder clay. The shells are often entire, and *in situ* clearly, and have epidermis on the sections.

Soil and gravel } 50 feet.
Boulder clay }
Fine sand, stratified, 20 feet.
Shell bed of blue clay, 7½ feet (bottom not reached).

This is on the farm of Drummore, of Clava, six miles east of Inverness, half a mile east of the river, and 200 feet above it.

Chas. E. De Rance, On the Relative Age of some Valleys in the North and South of England. *Proc. Geol. Assoc.* vol. iv. No. 4.

W. C. Lucy, The Post-Pleiocene Drift of Charnwood Forest. *Geol. Mag.* vii. No. 11.

Glacial striæ of Great Britain

1. De Rance, *Superficial Geology of Country about South-West Lancashire*, 1877, p. 47. Gives a list of twenty-one striæ on the south-west coast of Lancashire and Cheshire.

2. Morton, The Glacial Striæ of the Country around Liverpool. *Proc. Liverpool Geol. Soc.*, 1876–7, p. 284.

3. Mackintosh, Erratics in Llanarmon Parish, &c. *Quart. Jour. Geol. Soc.*, 1874, p. 712 footnote. Striæ are at Holywell and Caergwrle, and about Corwen.

4. Tiddeman, Ice-sheet in North Lancashire. *Quart. Jour. Geol. Soc.*, 1872, xxviii. 471.

5. Goodchild, Glacial Phenomena of the Eden Valley, &c. *Quart. Jour. Geol. Soc.*, 1875, p. 55. Excellent paper.

6. Ward, J. C., Glaciation of Lake District, &c. *Quart. Jour. Geol. Soc.*, 1873, xxix. p. 422.

7. R. Howse, The Glaciation of the Counties of Durham

and Northumberland, *North of England Institute of Mining Engineers*, vol. xiii., 1863–4, p. 170.

8. Hull, Geology of Country around Prescot, Lancashire. *Geol. Memoir*, 80° N.W. 3rd ed. 1882, p. 26. Striæ recorded. Direction W. 8° N.

9. Ward, Glaciation of South Part of Lake District. *Quart. Jour. Geol. Soc.*, 1875, p. 152.

10. Ramsay, Island of Anglesey. *Quart. Jour. Geol. Soc.*, 1876, p. 116. Striæ go S. 35° W. Describes local Welsh glaciers with striæ going west about Barmouth, &c., the striæ always conforming to the valleys. Wales was not over-ridden by a northern ice-sheet. The local glaciers never reached Menai Straits, but spread out in fans higher up. Anglesey was glaciated by ice from Cumberland.

11. Mackintosh, Great Ice-sheet in South Part of Lake District and in North Wales. *Quart. Jour. Geol. Soc.*, 1874, p. 174. Long list of striæ. The ice ignored configuration, crossing hills 2,000 feet high. Striæ in Wales are also given. An excellent paper.

12. T. McK. Hughes speaks of striæ near Bangor on the road from Friddodd towards Belmont. *Quart. Jour. Geol. Soc.*, 1879, p. 688.

13. On Map lxxix., north-east drift; striæ on limestone one mile and a quarter west of Whitford and two and a half miles south-west of Mostyn Station go south-east by east.

14. A. Strahan, On the Glaciation of South Lancashire, Cheshire, and the Welsh Border. *Quart. Jour. Geol. Soc.*, 1886, May 26.

Striæ

On the index to the Ordnance Survey of England, Wales, and Scotland, I place the following numbered striæ.

Wales:—

1. Ramsay, *Geol. of North Wales.* Near Yr Eifl E. 43° N. or S. 47° W.

2. Ramsay, Anglesey Striæ. *Geol. of North Wales*, p.

270. Mean direction 30°-40° west of south. Also Strahan, *Quart. Jour. Geol. Soc.*, 1886, p. 369, map.

3. STRAHAN, Striæ of North Welsh Coast, Conway to Holywell. *Quart. Jour. Geol. Soc.*, 1886, p. 369. Also Geol. Map, sheet lxxix., north-west drift, which shows striæ on limestone at the coast just east of Colwyn at three points, going south at Colwyn, and S. 30° W. one mile east of Colwyn.

4. MACKINTOSH, Hope Mountain; Striæ South-east. *Quart. Jour. Geol. Soc.*, 1874, p. 712; and STRAHAN (*l.c.*), also S. 15° E.

5. MACKINTOSH, Valley of Dee. *Quart. Journ. Geol. Soc.*, 1874, p. 712.

6. MORTON, Birkenhead, N. 20°-30° W. *Quart. Jour. Geol. Soc.*, 1862. HULL, *Trans. Manchester Geol. Soc.*, 1864. MACKINTOSH, *Quart. Jour. Geol. Soc.*, 1877. Also Oxton, Two Miles West of Birkenhead, N. 24° W. Bostock, *Rep. Brit. Assoc.*, 1870, and RICKETTS, *Proc. Liverpool Geol. Soc.*, 1876-7. N. 22½° W., N. 40° W.

7. MORTON, Liverpool, N. 15° W., N. 35° W. *Quart. Jour. Geol. Soc.*, 1862. *Rep. Brit. Assoc.*, 1870. Bootle, N. 28° W. READE, *Proc. Liverpool Geol. Soc.*, 1872-3.

8. MORTON, Wavertree, Three Miles East of Liverpool, N. 32° W. *Rep. Brit. Assoc.*, 1870.

9. READE, Crosby, N. 22° W., N. 40° W. *Proc. Liverpool Geol. Soc.*, 1873-4.

10. A. STRAHAN, Pool Hall Rocks, Cheshire, twelve miles SS.E. of Liverpool. N. 43° W.

11. A. STRAHAN, Farnworth, Two Miles North of Runcorn, W. 8° N. *Mem. South-West Lancashire*, 1876.

12. STRAHAN (*l.c.*), Runcorn, W. 8° N., *Mem. South-West Lancashire*, 1876.

13. RICKETTS, Thallo Heath, Eight Miles East of Liverpool, W. 40° N. *Proc. Liverpool Geol. Soc.*, 1869-70.

14. STRAHAN, St. Helens (north of Prescot), W. 30° N. *Mem. Geol. Survey, Lancashire.*

15. HULL, Horwich, W. 12° N. *Mem. South-West Lancashire.*

16. Tiddeman, Chorley, N. 22° W. *Quart. Jour. Geol. Soc.*, 1872.

17. Preston, Euxton, N. 22° W. *Quart. Jour. Geol. Soc.*, 1872.

18. J. Plant, Ordsall, Manchester, N. 40° W. *Trans. Geol. Soc.*, March 1868.

19. D. Mackintosh, Striæ about Ambleside. *Quart. Jour. Geol. Soc.*, 1874, p. 174.

20. Heyshaw, N., N. 10° E., N. 40° E. The striæ of Scotland are taken from the map in Geikie's Great Ice Age.

The striæ of the Lake District are taken from two papers of Mr. J. C. Ward, *Quart. Jour. Geol. Soc.*, 1874, p. 174 [in which the striæ are all reversed]; and *Quart. Journ. Geol. Soc.*, 1875, p. 152; also Mackintosh.

The region south of the Lake District is copied from a map of J. G. Goodchild (*Quart. Jour. Geol. Soc.*, 1875, p. 55), and still farther south from a map of Tiddeman (*Quart. Jour. Geol. Soc.*, 1872, p. 471).

Other striæ about the neighbourhood are copied from the map of Davis and Lees in their West Yorkshire, and from this map the striæ of the Aire glacier and those about Ripon, &c., are taken.

The striæ of Durham, Barnard Castle, and Darlington are taken from the Geol. Survey map of the district.

The striæ of North Durham are not noted, the references to them being too indefinite.

The striæ of Wales and Anglesey are given as noted by Ramsay, Keeping, David, and Strahan.

Those about Liverpool as noted by Mr. Morton.

Striæ of North Wales in eight places are given by Mr. Strahan (*Geology of Rhyl, Abergele, and Colwyn*, p. 39).

Some, as at Craigfawr, come from the north and belong to the great ice-sheet, while others come from the W.S.W.

Striæ of north-west of England and papers on the glaciation of Cumberland are given in *Proc. Cumberland Association.*

Mr. De Rance tells me that on the north side of the Lake)istrict striæ certainly cover the highest mountains, 3,600 eet, and run across them. Some striæ conform to the alleys, often going north, as Clifton Ward has shown.

The ice was 3,600 feet to 4,000 feet thick here, i.e. etween Keswick and Ambleside.

13

EXTRACTS FROM FIELD NOTE BOOKS

MEMORANDA AND BRIEF ESSAYS ON VARIOUS SUBJECTS CONNECTED WITH GLACIAL GEOLOGY

It was the intellectual habit of Professor Carvill Lewis to use every theory that came into his mind as a working hypothesis, and to treat it exhaustively, examining every detail bearing upon it in the field, and consulting all the publications upon it he could obtain. In the course of his investigations, therefore, he collected together all the arguments that could be urged and all the facts that could be quoted in support of the particular hypothesis under his examination and on its trial—dropping it at once when the balance of evidence seemed to him against its validity.

The following memoranda and brief essays must be read in the light of this method of study and be regarded as aids to thought rather than as statements covering the whole field of matured convictions.[1]

Inter-glacial periods

[The Scotch glacialists, Geikie, Peach, Horne, &c., hold that there was an inter-glacial warm period, quoting peaty deposits, both overlaid and underlaid by till. But we can easily imagine a marginal lake where trees grew, and which a slight oscillation of the edge of the ice would cover with till.

---

[1] Several of these extracts contain the fundamental ideas and observations which were afterward developed by Professor Carvill Lewis into the addresses on 'The Comparative Glaciation of North America, Great Britain and Ireland,' and, 'Some Important Extra-Morainic Lakes,' &c., given in Sections I. and III. of the present volume.—J. F. L

In Switzerland trees grow now at the very edge of the glacier. The boulder clay beneath the trees would be an aqueous boulder clay made at the bottom of a marginal lake while the ice was advancing. The trees would be killed by the cold and would fall into the lake, and the ice would afterwards advance and cover the peat-bog. The supposed inter-glacial beds are rare and local, as would be the case if they were made in marginal lakes. If a real inter-glacial period occurred we should find a constant horizon of trees, &c., extending over large areas.

The supposed two glacial periods in Switzerland are not founded upon evidence satisfactory to me.

The moraine is well defined north of Lake Constance. Outside of this is a flat area in Würtemberg covered by boulder clay, supposed to belong to the first glacial epoch. But is not this a marginal lake ?] (Consult the map by Fraas.)

There was only one glaciation.

Notwithstanding the various stratified and unstratified deposits of North Germany, Berendt (*Z. D. G. G.*, 1879, 4) holds that there was only one ice-covering.

The Rhine glacier deposited a series of stratified and unstratified drifts which he (*Z. D. G. G.*, 94) regards as a single inseparable deposit representing the ground moraine of the glacier.

Note on Submergence

[In Pennsylvania there was a glacial submergence of 180 feet at tidewater.

But higher up the Delaware River, where the river bed is now 50 feet above the sea, the glacial submergence was 180 feet above the present river. It is thus at Bethlehem, on the Lehigh. The explanation offered is that when the sea was 180 feet higher, and the rivers emptied into it farther inland, their beds were not so deep, but were higher in proportion then, as they are now. Indeed, in old times there was more disproportion in the elevation of river valleys than there is now. I mean the difference between the upper and the lower parts of their beds was greater then, and must have been so, for erosion is always cutting down the upper, and filling up the lower parts. I mean that just as the beds of rivers at their mouths were very much deeper than now (buried rivers), so their upland portion was very much higher than it is now.

To represent it diagrammatically, I take the Delaware River as it is and as it was:—]

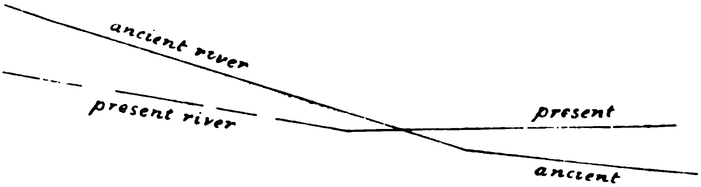


FIG. 48.—Diagram showing different Levels of the Ancient and Present Beds of the Delaware River.

H. MILLER, River Terracing. *Royal Phys. Soc.*, 1883, p. 263. Admirable paper on the subject, reviewing all the theories.

H. MILLER, On Boulder Glaciation. Good striated pavements. Glaciated about Edinburgh. Fluxion structure in till. *Royal Phys. Soc.* viii. 157.

H. MILLER, Tyndale Escarpments. *Nat. Hist. Trans.*, North Durham and Newcastle-on-Tyne, vii., 1880. Good.

Slight erosive power of glaciers. Quote. Snailborings due to weathering and snails, not pholas. Glaciers have failed to hold escarpments.

Supposed submergence of Great Britain during the Glacial Epoch

[I am not more fond of catastrophes than Sir Charles Lyell was. I have done my best to accept a theory for the English gravels which would simply require a gradual marine submergence, but I have been entirely unable to make the facts fit the theory. I find the writings of those who first studied these phenomena nearest the truth. I find with them *Reliquiæ diluvianæ* and *débâcles*, but not quiet submergence. I agree with them that a sudden and mighty rush of water swept across the country and then was over. I sympathise with those who believed that a convulsion of nature occurred at that time. I believe that British geology would be much farther advanced if, when Mr. Trimmer announced his discovery of shells on Moel Tryfaen, his theory as to their origin had been accepted, instead of that of a marine submergence proposed by others I believe this doctrine of a post-pleiocene great marine submergence in Britain to be the most pernicious one ever propounded in geology.

For the last fifty years it has retarded the investigation of post-pleiocene phenomena all over Europe and America, and it is only lately that a few foreign geologists have begun to throw off this yoke. When England is once and for ever rid of it, the drift will no longer be a byword, and a synonym for confusion and helplessness, but will take its rank among the orderly strata of the earth's crust. That once accomplished, post-pleiocene deposits will become of the highest interest, as having the most direct bearing on the advent of the human race.]

Pre-glacial submergence in Scotland

An interesting shell bed on the river Nairn in Scotland, at the elevation of 500 feet, has been described by Mr. James Fraser (first notice of a post-tertiary shell bed at Clava in Nairnshire, indicating an Arctic climate, and a sea bed at the height of 500 feet. *Edin. Geol. Soc.* 1881, p. 136). Dr. Crosskey has recently visited this place, and confirms Mr. Fraser's description of it. An undisturbed mass of clay occurs there, full of unbroken delicate marine shells, with united valves; over it, separated by a sharp line, is a sand bed, and over this, unconformable to it, and sharply separated from it, is a large mass of stony till. This old sea-bed has been protected from glacial erosion by surrounding crags of rock. No erratics are known in this sea-bed, which may therefore be pre-glacial. It is an old estuary, perhaps, of similar age to the pre-glacial shell bed of Speeton (100 feet high) and the pre-glacial marine and estuarine beds of the Norfolk coast.[1] There is no evidence that it is inter-glacial, or that the submergence it indicates was not anterior to the elevation which brought on glaciation.

Further remarks on submergence

Jamieson (*Quart. Jour. Geol. Soc.*, 1865, p. 171) says, 'It is a remarkable fact that, although marine fossiliferous beds may be traced in many places to a height of 200 or 300 feet above the sea, they are nevertheless totally absent to all appearance along many of the valleys in the interior of the country at much lower levels.' [Glaciers occupied the mountains during a submergence, which ended before the glaciers retreated? Or did glaciers clear them out, i.e. were the glaciers latest? It now seems clear to me that the maximum submergence occurred before the maximum glaciation, and also that the maximum elevation occurred at the very beginning of the formation of the glaciers. Climatic changes were slow to influence the glaciers. I believe that the main advance of the glacier was made during a period which was warm, and during a period when the sea encroached upon the land farther than at present. There would thus be greater evaporation than at present, on account of the greater quantity of water vapour, and greater precipitation on account of the ice-sheet. Yet great precipitation in the form of snow is the one desideratum for the growth of glaciers. The interior dry plain of North

---

[1] The Arctic character of the shells in the Weybourne crag accords with that of the shells in the pre-glacial bed at Speeton. No inter-glacial marine beds are known on the Holderness coast. Naturally the shells on the northern coast of Scotland would be more Arctic than they would be in England.

America was by its dryness alone an effectual block to the ice-sheet. Mr. McGee has shown that the ice-sheet must have advanced by addition to its edges. Whitney has argued that a warm climate was contemporaneous with the glacial period.

If the greatest extension of the ice was later than the greatest submergence, then the torrential gravel-floods caused by the melting of the ice must be newer than the shell-bearing marine gravels, and may thus contain rolled shells and flints.] See the Memoirs and papers of Hugh E. Strickland, by Sir William Jardine, p. 90, 'On the Deposits of Transported Materials usually termed Drift, which exist in the counties of Worcester and Warwick.'

General Drift—Local—Fluviatile.
Quartzose Flinty.

'The quartzose drift,' largely derived from the conglomerate of new red sandstone, extends over the middle and northern parts of Worcestershire and into Warwickshire, Staffordshire, and the north of England, and contains rocks from Shropshire, Staffordshire, and the north of England. (Chalk flints are rare.) It contains no bones or fossils. As we go north the boulders increase in size, and there was clearly a current from north to south. 'The flinty drift,' abundant in East Warwickshire, and northward towards Derby, and about Rugby, is destitute of mammal remains, and came from between the north-east and south-east. This does not exist in Worcestershire, and the Vale of Shipston is its limit to the west. The boundary between the two drifts is the line between the lias and the new red sandstone.

'Local drift' is in patches in the vales, and is due to old rivers; it is made of oolite, marlstone, and lias.

'Fluviatile' drift contains bones and fresh-water shells, it is seen in the Avon Valley, and was formed when the Avon flowed at a level 40 feet higher than now.

Murchison held the general drift to be due to marine currents flowing from Lincolnshire to the Severn Valley, bounded on the east by an oolitic escarpment. Flinty drift came from the east side of the chalk hills, and quartzose from the west side of them.

On the nature and origin of the various kinds of transported gravel occurring in England, *l. c.*, p. 105.

The oolitic hills are free from gravel; but streams from them extended through transverse valleys of oolitic range, and got into the Thames Valley, capping the hills at Oxford and Henley. The causes transporting gravel were transient. Gravel without chalk is found north and west of Warwickshire Avon, and gravel with flints is seen between the Avon and the oolitic hills.

The origin of the flints found in drift

As to the origin of flints in the drift there are two.

(1) Flints from the bed of the Irish Sea which belong to the chalk extend from North-east Ireland to West Scotland. This flint is, as Professor Hughes has remarked, 'not flint ice-borne from chalk, but rolled gravel flint, often with the ferruginous rusty gravel stain remaining' (Hughes, Notes on the Geology of the Vale of Clwyd. *Proc. Chest. Soc. Nat. Sc.*, 1884, p. 26).

[This has been taken up by the ice-sheet, together with shells, and transported southward to Moel Tryfaen, to the north coast of Wales, Anglesey, and to the north Cheshire plains, Lancashire, and Halkin Mountain.

(2) Flints from the east of England, the wolds of Lincolnshire and Yorkshire, &c. These were not ice-borne, but carried by a powerful stream flowing south-west from the mouth of the Humber to the mouth of the Severn.

They occur not only all across the low part of central England, but also in South Wales, west of Cardiff. They were probably carried by a stream 200 feet deep, perhaps 250 feet deep.]

Marine shells in the drift

[I examined Dr. Crosskey's collection of shells from the glacial clays. They are of two entirely distinct classes.

(*a*) These are beautifully preserved shells and barnacles, which either singly, or grown to glaciated boulders, lie in an undisturbed marine clay, which, at elevations of less than 50 feet above the sea on the Scotch coast, overlies till or fills hollows in the till.

These shells are often large, such as certain pectens, and although frequently very thin and delicate, are unbroken and well preserved. They are gray, and filled with mud.

Generally, as Dr. Crosskey informed me, they lie from about sea-level up to 20 feet above the sea-level. Barnacles are common, and these are often seen attached to glaciated stones which have fallen into the mud. The clays containing these beautiful shells are entirely undisturbed, and were formed at the close of the glacial epoch, while the sea was cold. They have a northern, almost Arctic, facies.[1]

Dr. Crosskey pointed out that the shells collected in clays on the east coast of Scotland indicate colder conditions than those on the west coast, and that this is still the case. Some of the shells now living on the east coast of Scotland belong to a colder race than those on the west coast. They resemble more nearly the Norwegian shells, and show that the waters of the North Sea are colder than those of the Atlantic. That precisely the same relative condition of the two seas existed at the close of the glacial epoch as now exists is an argument against theories of changes in elevation, or in the distribution of land and sea since the glacial epoch; it is also an argument for the recency of the close of the glacial epoch.

The clays which hold these shells often lie in river valleys, showing that the drainage was the same then as now.

(*b*) The second class of shells are entirely different in appearance, in age, and in position. They might be described as 'shell pebbles,' since they are all transported and waterworn fragments. They are white, generally fragmentary, and almost always rolled and rounded. They lie in drift, sand, gravel, or till, and are to be classed with pebbles. They do not lie in the position in which they lived. They occur at all heights, up to nearly 1,500 feet, occurring as high as any drift gravels occur. These are the shells of Moel Tryfaen, of Macclesfield, of Blackpool, and of Loch Lomond.

---

[1] O. Torell says they are identical with species now living in front of the Spitzbergen glacier (*Trans. Roy. Soc. Edin.* xxiv. 627).

At Moel Tryfaen and at Macclesfield (perhaps, also, at the other two points) they lie in rounded gravel and sand among the pebbles, and have been transported from seaward, just as at Durham the flints have been similarly transported. They are associated at Moel Tryfaen with flints from Antrim.

They only occur where the ice-sheet moved inland from the sea, I think. It is a great mistake to confuse together and refer to a common cause these two quite distinct classes of shells.

This second class of shells have a much warmer facies and belong to deeper water than the first class. They indicate a sea very little colder than the present sea. They are older than the first class of shells. They were, as their height indicates, deposited either at the time of extreme glaciation or of extreme submergence according to the theory adopted. If at the period of extreme glaciation, as I suppose, then the sea at that time was almost as warm as it is now, and much warmer than it was at the close of the glacial epoch. At that later period it would naturally have become cooled by the melting ice (and would also be less salt, as, I believe, is also indicated by the shells of the first class). A warm sea and high land is sufficient cause for the glacial epoch.

The shells of the second class were, I conceive, frozen into the foot of the advancing ice. (See similar remarks by T. Belt, *Quart. Jour. Geol. Soc.*, 1878, p. 396.)

The shells of the first class from Scotland appear to be closely analogous to those in the marine clays of Maine (vide Stone, &c.), and to those in the till at Montreal (vide

Dawson). At each of these three places the elevation is less than 30 feet above the sea, and all are in northern latitudes, north of 50°.]

On shells in the drift consult:

1. Forbes, Fauna and Flora of the British Isles, *Mem. Geol. Survey*, i. 383. He speaks of the fragmentary condition of the shells, and is puzzled by it, suggesting that it is due to the ploughing up of icebergs or the rush of ocean currents.

2. T. M. Reade, On the Drift Beds of the North-west of England, *Quart. Jour. Geol. Soc.*, 1874, p. 27. Valuable paper. Gives lists of shells and localities. Shows that the shells are much rolled, and that 'they could not possibly have lived together on the same bottom, some being peculiar to sand, others to mud; some to rock, others to shingle; some requiring deep water, and others shallow; so that the conclusion is irresistibly forced upon us that they must have been to a large extent transported.' He thinks coast ice has done this rolling. These shells occur at Liverpool, Blackpool, Warrington, Chester, &c. With the exception of three species all may 'be described as Irish Sea shells,' but in all they have a more northern facies than the shells now living in that sea.

Some southern forms (Venus and cardium) also occur, while Arctic forms (*Astarte borealis*) are with them. Such a mixture of northern and southern species is now found on the sea-bottom near Cape Cod (p. 35). A climate, such as that now in North Labrador, is indicated (p. 36).

The same paper states that the shells from Fifeshire and Perthshire (shells of the first class) belong to colder climates, and Dr. Otto Torell (*Trans. Roy. Soc. Edin.*) says these latter are identical with species now living in front of the great glacier of Spitzbergen.

Mr. S. V. Wood, Junr., has shown that the shells in East Anglia overlying the Cromer Forest bed indicate a crag-like fauna, gradually becoming Arctic and afterwards Celtic; and that the Bridlington beds have shells of more Arctic character than the Lancashire clays or Clyde beds (*Quart. Jour. Geol. Soc.*, 1869, p. 97).

3. R. D. **Darbyshire**, Middle Pleistocene Gravel in Lancashire, and the Shells in it. *Quart. Jour. Geol. Soc.*, 1874, p. 38. Describes a hill of gravel near Leyland Station, on the eastern side of the Bolton and Preston Railway, which contains rolled fragments of shells. Flints are rarely seen, while mountain limestone and many other rocks occur. Some of the shells are of northern, and some 'of markedly southern origin' (Venus, cardium, mactra). The shells are like those at Macclesfield and Moel Tryfaen. With a few exceptions, the fauna is much like that of the present seas of the western shores of Great Britain. He thinks the shells did not live where they are found. In the discussion Dr. G. Jeffreys did not think the shells were truly Arctic.

4. According to Professor Ramsay (*Quart. Jour. Geol. Soc.*, 1876, p. 116), fragments of shells occur in the till in the coast cliff at Beaumaris.

5. For a good paper on the submergence of East Anglia see W. H. Penning, East Anglia during the Glacial Period (*Quart. Jour. Geol. Soc.*, 1876, p. 191). The land sank from 400 feet to 500 feet, and a current of water ran from the North Sea to the Atlantic (from the Wash to the Severn ?).

6. W. **Shone**, On the Glacial Deposits of West Cheshire, with Lists of the Fauna of the Drift. *Quart. Jour. Geol. Soc.*, 1878, p. 383. Rolled shells, sorted by water, according to weight, occur about Newton (between Manchester and Liverpool). They are not *in situ*, and the valves of bivalves are never joined. The shells at Newton and Dawpool are identical with those at Liverpool described by Mackintosh. The shells (and the gasteropods containing silt with microzoa) are spread over a wide area (Lancashire, Cheshire, Flintshire, Denbighshire, Shropshire, Staffordshire, and the Isle of Man). At Macclesfield and at Arnfield, Cheshire, 600 feet high, they are the same as at the sea-level at Dawpool.

7. C. E. De Rance, Superficial Geology of Country adjoining the Coast of Lancashire, *Geol. Mem.*

8. D. Mackintosh, High-level Marine Drifts. *Quart. Jour. Geol. Soc.*, 1881, p. 351. Literature of the Moel Tryfaen deposit is given. It is shown to be associated with granite, &c., from the north. A similar moraine deposit is described at Frondeg, west of Wrexham, Denbighshire. It is a good paper as to facts, though mistaken as to theory.

9. Close, *Geol. Mag.* vol. i., Dec. 11, 1874. Glaciated shell fragments with limestone boulders from the north-west occur at 1,200 feet on Three Rock Mountain, near Dublin.

10. G. Jeffreys, Marine Shells at Heights above the Sea. *Quart. Jour. Geol. Soc.*, 1880, p. 351. Gives a complete list of the Moel Tryfaen shells.

Eskers

[Eskers are phenomena due to the melting of the ice and the circulation of subglacial waters, and are not due to the action of a glacial sea.

I have searched for this glacial sea all over England and in North Germany, and have examined many of the localities supposed to prove its former existence, but have utterly failed to find any proof in support of the hypothesis.

This sea is supposed to have had very remarkable properties, and to have been wholly unlike any known sea. It made till and it eroded till; it filled some regions with stratified drift, while others it cleared utterly of all drift, whether stratified or unstratified; its icebergs made striæ and its waters washed them away; it rose to 200 feet in some places, and to 3,000 feet in others only a few miles distant.]

The fringe

[I have in many places noticed both with the great ice-sheet of North America and that of England—as also with the local glaciers of England—that outside of the drift hills forming the moraine there is a fringe of boulders and of till, with glaciated pebbles, lying on rock little, if at all, glaciated.

Thus the edge both of the fringe and of the moraine should be mapped.

For example, the moraine of the Wensleydale glacier is between Ripley and Wormald Green, but till continues to Harrogate. So in Lancashire a good example is perhaps on Map lxxxi., north-west (drift), where the line of sandhills lies two miles west of the edge of the till, &c.]

Marginal lakes and the fringe

[On plotting on the Index map the moraine, and the localities of drift outside of the moraine, both on the west and east sides of the Pennine Chain, some extremely important facts appear.

The moraine has fringe with marginal lakes (extramorainic lakes) in those places only where rivers flowed *towards* the moraine and into it. Where this was not the case the moraine sharply defines the line between the glaciated and non-glaciated area. Where a stream was dammed back by the front of the ice, however (as the Marjelen See), there boulder clay, full of scratched erratics, accumulated in lakes due to the filling up of the river valleys. These lakes were temporary, and were drained when the ice retreated.[1]

---

[1] The fringe should therefore only occur where streams flow, or once flowed, toward the glacier. In all cases where the fringe occurs in localities where streams now flow outward from the moraine, I believe it can be shown that the glacier has reversed the drainage so that, whereas in pre-glacial times the river would flow towards the ice, in post-glacial times it flowed away from it. Such a reversal of the flow of a river could naturally only occur where the watershed into a valley draining in the opposite direction was low and short, so that the river could readily cut a new channel through it. At first thought it seems a remarkable feat for a river to suddenly begin flowing backward and up stream, but I can show that this feat was actually accomplished in many cases both in America and Europe. A river having begun to flow backward, while the ice-wall barred its forward progress, continued to do so after the ice-wall had retreated and the terminal moraine

The Marjelen See is temporary and lifeless. The fringe is now at length explained. Professor Wright has shown that the Ohio was dammed up at Frankford (?), and so caused high-level gravels farther up the river and its tributaries. All the troublesome boulder clays in the Pennine area are now explained. On the west side the moraine dammed up many streams, the Real, near Rochdale, the Ettaren, near Stockport, about Bugsworth, the Dane at Congleton, and the valley running south at Congleton to the River Trent. In the latter case the lake overflowed southward, and the débâcle passed down the River Trent to Lichfield, &c. The Rivers Roden and Tern in Shropshire drained the ice-sheet mainly.

The Aire glacier dammed up the wharf at Skipton, and made a fringing lake in the limestone valley extending from Skipton towards Bolton. It also dammed up the Bradford Beck at Shipley, and made a marginal lake extending in the valley from Shipley to Bradford[1] (thus accounting for the boulder clay described in *Geol. of Yorkshire*).

On the east side of the Pennine Chain the York glacier dammed up the Nidd near its confluence with the Ure; and a marginal lake extended up the tributary Oak Beck as far as Harrogate, making the boulder clay there, and the gravels at Knaresborough, Goldsburgh, and Ripley

---

took its place. I shall produce numerous instances to show that a river often found it more difficult to cut through the moraine than to cut through solid rock. In fact, glacial till is actually tougher than rock. I have often been told by railway contractors in America that it is harder work and costs more money to cut through 'hard pan' (till) than through rock. Apart from this, if a river ever begins to cut a channel in a certain direction it is very apt to pursue the conservative method of continuing to run in the same rut.

(Newberry, Reversal of Drainage in Ohio. Wright, Dam of Ohio. Carel and White in Pennsylvania. Old gorge at Niagara, gorge at Minneapolis, &c.) Reversal of the Kander, the Rhine, new cutting at Falls of the Rhine, reversal of the Derwent and of streams at Bridlington and Haddockstones. Aire? Blackwater. Red River.

[1] It also dammed up the River Worth, making the fringe about Haworth, &c.

(thus explaining the doubtful boulder clay at Harrogate at 375 feet). Finally, the North Sea glacier made marginal lakes in Holderness[1] (see Reid, and Lamplugh) and did the same and sometimes reversed the drainage about Scarborough and Whitby (Fox-Strangways, *Geol. of Scarborough, &c.*).

Its most important and far-reaching lake was that made by damming up the mouth of the Humber. This made a great irregular lake, filling the land drained by the Humber, the Trent, the Wharfe, the Hull and the Ancholme, the Don, the Calder, the Aire, and the Ouse, up to an elevation of nearly 300 feet.

(Did the southward extension of this glacier also dam up the Norfolk rivers and the rivers going into the Wash? Yes.)

The York glacier dammed up the stream east of Coxwold to make the fringe drift I saw at Ampleforth in the valley.

(The great Humber lake probably overflowed in débâcles into the Avon and Thames Valleys?) I must map and name all of these lakes. Compare with Lake Agassiz, as described by Upham.

The York glacier thus ended in deep water, and icebergs of large size could easily break off and float down from the end of the glacier at York into the various arms of the lake. These lakes were as irregular as the Lake of Lucerne.

All the phenomena of the fringe in Pennsylvania are explained by marginal lakes; the large far-carried erratics stranded on hills; there is no true till, and no striæ are seen on the rocks, &c.]

Traces of ancient rivers

[When the level of the land in reference to the sea was higher than it is now, what traces would an ancient river, should it have traversed it, leave to be seen to-day?

---

[1] And a lake in Eskdale.

1. In the tidal portion of the present river there would be a deposit of diluvium on top of which the present river flows, while the rock-bed would be far below. This is the case with most rivers—with the Delaware, the Hudson, and the rivers of England, Wales, Scotland, and Ireland. Everyone admits this. The deposit is deepest nearest the sea.

2. In the upper part of a valley, where the present river has cut its way below the old bed, traces of that old bed should appear above the present bed, and the higher we ascend the river the greater will be the difference between these levels. This is a matter that geologists do not generally appreciate, and is the special point upon which I wish to insist. The cutting power of a river near its source is much greater than elsewhere, and diminishes gradually as we descend, until at last a point is reached, where the river stops cutting and begins to fill. This is where its bed reaches sea-level. But the upper part of the river, the cascade part, is where the cutting is most rapid, and where the greatest difference in level between the ancient and the modern bed will be seen. A gravel bed, therefore, which in the mountainous part of the river lies 100 feet above it, and 750 feet above the sea, does not imply, as many geologists suppose, a depression of the whole country to 750 feet, but quite the reverse; an elevation of it may be 100 feet and, allowing 25 feet for greater depth of the river (for all our rivers are diminishing in volume), a cutting action of 75 feet through and beneath the ancient bed. That some rivers have done much more than this amount of cutting since the glacial epoch is proved by many facts, and among them by the gravels above the Susquehanna River, in Pennsylvania.]

Scotch boulder clay

[Two very distinct deposits are said to occur in Scotland: a lower, very hard and compact till, and an upper, looser, and more sandy boulder clay. The line between the two is often quite sharp and well marked, and they are sometimes separated by a deposit of sand, which rarely contains shells. These are held to represent two advances of the glacier and an intervening inter-glacial epoch.

I suspect that here, as in America, the lower till is a ground moraine made during the advance of the ice, and that the loose upper boulder clay was dropped by the ice during its retreat. The water due to the melting of the ice made the intermediate sandy deposits. At low levels a submergence of 500 feet may, in a few places, have permitted the introduction of some marine shells, but generally these were derived from the glacier itself, which had passed over a sea-bottom.

In Lancashire the till at Crosby marks the advance of the ice and the boulder clays (including all of Hull's three divisions), its retreat, which took place in water.

Drumlins belong to the till, and moraines of recession to the boulder clay. When the glacier retreats on land, the boulder clay is sandy, rubbishy, or gravelly, and has few striated boulders, but when it retreats in water, it forms a tough, true boulder clay, full of finely striated erratics.

Mr. T. M. Reade told me he saw no evidence of an interglacial period in Scotland or elsewhere.]

Pleiocene of England

A knowledge of the pleiocene is necessary in order to understand glacial conditions in Great Britain. See—

1. PRESTWICH, On the Structure of the Crag Beds of Norfolk and Suffolk. *Quart. Journ. Geol. Soc.*, 1871. In three parts: (1) The Coralline Crag of Suffolk. (2) The Red Crag of Essex and Suffolk. (3) The Norwich Crag and Westleton Beds. He says (p. 134): 'In the pleiocene period the sea began to cover the eastern counties, while the land rose to the south, and there is evidence of ice-action at the

earliest period of the coralline crag, since a large block of (Scandinavian ?) porphyry lies in the basement bed at Sutton, with oolitic remains.' Many interesting particulars are given in this series of three papers.

Extra-morainic lakes in America as illustrative of those in England

Professor J. E. Todd, in a paper on 'The Origin of Extra-moraine Till,' holds that it is due to lakes dammed back by ice. Arguments for its glacial origin are:—

1. It is indistinguishable from subglacial true till, unstratified.
2. The rocks below it are striated.
3. Osars occur in it, as in Minnehaha, Jerauld, and Brulé counties, Dakota.
4. It differs from the overlying red stratified clay of aqueous origin.
5. The till is thicker and higher at its outer margin, as if it were a degraded moraine.

For the glacio-natant theory we have:—

1. Traces of stratification.
2. Striæ rare and of variable direction.
3. It passes insensibly into the overlying red clay.
4. No moraines occur with it. Streams are not altered by this drift.
5. Underlying formations are not disturbed.
6. The western margin of the drift in Nebraska is nearly horizontal, 1,600 feet. As to width, it is from one to six miles in Pennsylvania, central Wisconsin, and along the Missouri between the White River and the Niobrara; while in the Mississippi and Missouri valleys it becomes 200 to 250 miles broad.

[Prof. Todd sent me this paper for criticism, and I answered, October 23, 1887, that, had it not been for recent observations I had made about Birmingham, I should have agreed with him.

Recently I had found in the 'fringe' region of England evidence of a much more ancient glaciation; so old indeed that erosion had removed almost all the deposit and obliterated the striæ. Perched erratics occur above any possible lake. Is not this till due to an old glacier, and the red clay to an extra-morainic lake? Are they contemporary deposits? I find that the glaciers of the first epoch came from more southern centres than those of the second ice period.]

The three Rhines

[A GEOLOGICAL STUDY]

[Rivers, like women, are most beautiful when young. The three Rhines, that of Europe, of Ireland, and of America, are all post-pleiocene. There is a good reason for everything both in this world and out of it. A good reason for every feature in the landscape, which is due to no accident. Every hill has a certain shape, every waterfall a fixed place, because of certain facts and certain laws, which absolutely predestined their form and position.

There are old rivers and young rivers; some are as old as continents, and far older than the mountains, and some are quite young. Mountains often rise around old rivers, while they pursue the even tenor of their way. The rivers of the Appalachians and of India have cut through mountain ranges.

Old rivers have large channels and wide drainage areas, indicating the ancient slope of the land.

New rivers have none of the accessories of the well-furnished and wealthy old ones. Wild and headlong, they dash through gorges, and are very industrious cutting their way. Old ones have finished work, and, at all events, are cutting slowly—are usually levelling off and filling up their channels. Young ones are generally small, rocky, and impassable for large boats. But it sometimes happens that an old river will desert its old ways, and will go into partnership with a young one, and begin life anew. The old river brings all its mass of waters drained from a large area through many ages, and gives them to the young river, which, in its turn, brings beauty and vigour to the landscape. The old river is rejuvenated and beautified, and the young river is given all the size and dignity of an old one. Such instances are rare, but have always been appreciated. This rare continuation has happened, I believe, in the case of the three famous rivers: the Rhine of Germany, the 'Rhine of Ireland,' and the 'Rhine of America.' The interesting portions of each river where scenery and size combine are: first, the region between Coblentz and Bingen; second, that between Cappoquin and Youghal; and third, through the highlands of the Hudson. These three parts are the young parts, all post-pleiocene; the other portions are old. In all three cases an old river has left its course and flowed in an opposite direction. Let us now examine the evidence. The Rhine has had a remarkable history. The upper part flowed into the Danube, the middle part into the Mediterranean, and the lower part into the Baltic.

A remarkable series of events which occurred in the glacial epoch changed all this. The elevation of the Jura shut off one outlet, a glacier in Upper Suabia stopped up another, and the Scandinavian ice-sheet blocked up the third. The three rivers struggled to be free. They agreed to unite in self-defence, and together to cut a new outlet to the sea. At first they were completely blocked; at no point could they get out, and could thus only form great lakes. Of these they made two. One covered Holland and Belgium, the other Mayence to Basel. The three rivers were the Danube, the Main, and the Moselle, portions of each of which make the modern Rhine. The Danube was choked by a moraine, and the old Rhine flowed through the Klettgau and the Sandgau. The Falls of the Rhine are new.]

APPENDIX A

INTRODUCTORY NOTE

It is no secret that some of Prof. Lewis' theories, so far as they have been understood by those who heard the papers he read before the British Association, and by those who had opportunities of conversing with him, have not met with general acceptance among English geologists.

One geologist, however, Mr. Percy F. Kendall, F.G.S., lecturer on science at the Stockport Technical School, before he became acquainted with Prof. Lewis, had been brought by his independent studies to the same general conclusions with regard to North-west England. He accompanied Prof. Lewis on several of his excursions, and has subsequently carried on extensive investigations in that region along the lines which, I believe, Prof. Lewis himself would have followed.

Mr. Kendall has kindly placed at my disposal a series of unpublished MSS., in which he has recorded his researches and the results which he believes that they establish.

A brief account of the way in which Prof. Lewis' interrupted work has been practically carried on by a geologist in sympathy with him will, I think, serve to illustrate both the theories he formed and the facts he collected, although, of course, his complete agreement either with the observations made or the conclusions drawn from them cannot in any way be assumed, and various points of difference will indeed be observed.

I have, therefore, extracted from Mr. Kendall's MSS. some salient passages which have a direct bearing upon the contents of this volume, and placed them together in this Appendix.

It is right to state that the extracts I have made do not represent Mr. Kendall's views in any complete form, and do not contain in full the varied arguments by which they are supported.

It must also be added that the choice of extracts has been determined by their relevancy to the subjects under -sion, and not by any principle involving my personal op and that I leave them to speak for themselves witho intrusion of any expressions either of assent or dissent.

H. W

I

THE EXISTENCE OF LAND-ICE IN EAST LANCAS AND CHESHIRE—INFRA-DRIFT SURFACES

(Rejecting the theory that a submergence of consi extent both in depth and area took place during the epoch, Prof. Lewis was always searching for traces of the of land-ice within the regions bounded by his great te moraine. According to his non-submergence theory, the drift surfaces ought to yield signs of the passage of the i glaciated blocks of local rocks ought to be found intermingle foreign erratics in the various deposits accumulated l moving glacier. He regarded East Lancashire and Chesl a district in which his theory could with special distinct brought to the test of facts, since, according to his views, glacier must have filled the Irish Channel and pressed dow the plains from the north-west towards the south-east.

As I have already remarked in the introduction to this v since Prof. Lewis' death some very notable sections have exposed, to which he would certainly have appealed as evidence in his favour on these important points. Indeed, I he would at once have crossed the Atlantic to examine the

Mr. Kendall has paid great attention to these section his general interpretation of them is, I believe, very m accord with that which Prof. Lewis himself would have I therefore extract a full account of them from Mr. Kendall's

H. W.

THE LEVENSHULME SECTION

A section about a mile in length was exposed in a r cutting running nearly due east and west between Fallowfie Levenshulme, near Manchester.

It exposed the following rocks—from west to east—T pebble beds, Permian marl, Permian sandstone, and coal measures consisting of marls with ten bands of fossiliferous spirorbis limestone. The whole series was covered by an uninterrupted sheet of boulder clay. The solid rocks had evidently suffered considerable erosion in glacial times, and masses of rock of various dimensions had been torn off and carried as boulders in an easterly direction. The pebbles out of the Triassic rocks were traceable for the

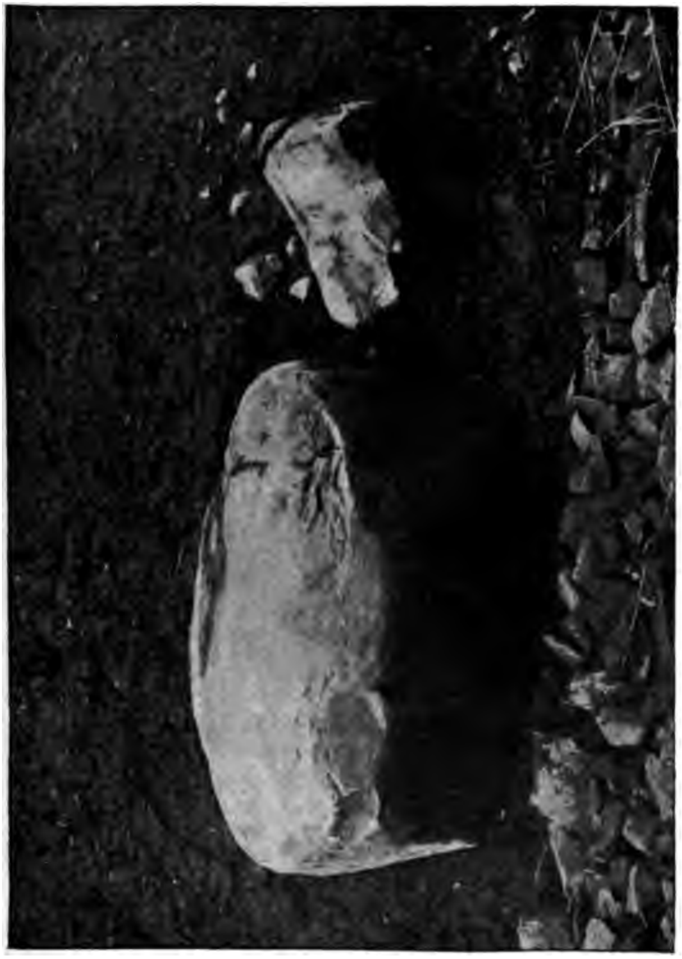


FIG. 49.—Scratched Boulder at Levenshulme.

full length of the section, and fragments of the sandstone were dragged over on to the Permian marls. Concretions from the marls were found well striated in the boulder clay over the Permian sandstone. The sandstone was too soft to bear transport in recognisable boulders, but its end was pulled over the junction with the coal measures.

On the coal measures the pulling over of the soft marls was very striking, but the most remarkable evidence was afforded by the limestone bands. At the first outcrop, and from each and every successive one, a stream of boulders took its origin and trailed away to a distance of two or three hundred yards in the boulder clay. Many of these boulders were quite sharp and angular, but the majority were scratched and abraded, and the angles were rounded. About 50 yards from the most westerly outcrop a group of boulders occurred, for a full appreciation of the importance of which I am indebted to my friend Mr. J. W. Gray, F.G.S. The central figure in the group was a magnificent boulder of coal measures sandstone of a type not occurring within miles of the spot. This stone was scratched upon every visible face, and it was separated from the very even surface of the underlying red coal measure marls by about 2 inches of dun-coloured boulder clay. In contact with its eastern end was a boulder of the local limestone, uptilted at an angle of about 30°, and in front of this a mass of worked-up marl was seen packed beneath the elevated end.

Other stones, such as one or two large pebbles of granite and several small blocks of limestone, were packed in the clay round about the larger boulders.

Finally, it was observed that the great sandstone boulder was scratched lengthwise upon its upper surface, the scratching having been inflicted by some agent moving from north-west to south-east. There was another and fainter set of striæ, which had a more westerly direction.

It is quite clear, from a consideration of the facts enumerated, that we have here a great boulder arrested in the very fact of erosion. The sandstone block had been driven against the limestone reefs, and had torn off several masses and ploughed through the soft marls, bearing them in front of it until the obstruction became too great to be overcome, and thus the mass was brought to a stand.

The light which this single illustration throws upon the whole question of transport and erosion can hardly be over-estimated.

The scratches on the surface of the great boulder agree closely in direction with a set I observed in a striated rock surface at the top of the Permian sandstone, distant about a mile and a half, viz. N. 60° W.

THE MANCHESTER AND LIVERPOOL SHIP CANAL SECTIONS

On the Manchester Ship Canal clean-cut sections may be seen in which the junction of the glacial series with the underlying sandstone is displayed in continuous sections of a mile and upwards. . . . The infra-glacial rock surfaces may be conveniently classified under four categories.

1. Glacial sands and gravels resting on waterworn surfaces of sandstone.
2. Boulder clay on an irregular surface of hard sandstone.
3. Boulder clay on a striated surface.
4. Boulder clay on crushed sandstone.

1. The occurrences of this class are rare, and in general of small importance, but there is one which will presently be described at length in the section at Bob's Bridge.

2. I have observed but two examples falling under this category. One was in a deep rock-hollow below the sea level at Ince, where the canal cutting runs across the foreshore.

The sandstone there had a flowing contour, but on minute examination I discovered that its surface presented irregularities of, perhaps, an inch in height.

A second case, of a different and bolder character, was well displayed in the excavation for the Irlam locks. Here the sandstone surface was positively rugged, and extremely hard till was packed into the hollows (5 or 6 feet in depth) as if it had been forced in under immense pressure. This appearance was only observable for about 20 yards, and on either hand the more normal appearance of crushed sandstone was visible. But even the till in these hollows contained tongues and pockets of ground moraine entangled in the mass.

3. The solitary example of a striated surface was situated about 200 yards to the north-west of the River Gowy, near the site of Stanlow Abbey. The striæ ran, as nearly as could be determined (the block had to be removed in order to show them), north-west.

It is desirable that I should here correct a mistake which might be productive of error at some future time when the means of correcting it have gone by for ever. A recent writer[1] states that glacial scratches occur all the way from Mode Wheel to the middle of Stickin's Island.

Now, through the whole distance mentioned—about three miles—only one small patch of glacial deposits have been met with, and on the particular spot selected for photography, as well as throughout almost its entire length, the rock was covered by river gravels, and the grooves, which were mistaken for glacial striæ, were just such as a river normally produces. They were irregular and often deeply undercut, and otherwise displayed striking characteristics, which would differentiate them from true glacial markings.

4. This division includes the most widely prevalent, and perhaps the most unimpeachable evidences of the action of land-ice that this district affords. It has received very inadequate notice hitherto, though it has not escaped the vigilance of Mr. Mellard Reade, to whom belongs the credit of first recognising that the crushed masses of sandstone, 'packed rubble,' as he calls them, constitute a species of ground moraine.

This deposit is characterised by the following peculiarities:—The sand is entirely devoid of stratification; it is always of the same character as the underlying rock, and, in certain cases, can be shown to exhibit the same minute local variations as are displayed by the rocks beneath it.

Nests and patches of gravel, and even of hard till, are occasionally included, and foreign stones are usually present, accompanied in one or two cases by identifiable fragments of marine shells.

I have seen in these fine cutting sections, for the distance of half a mile or a mile at a stretch—as, for example, at Malley Common—a mass of crushed sandstone intervened between boulder clay and the solid rock. In this material foreign stones were plentiful, and at the same time there was an entire absence of stratification. The evidence was, to my mind, clear that no rearrangement by water had affected the deposit.

One small portion of the Malley Common section I studied closely, and from this the photograph (fig. 50) was taken.

A sandstone surface rises with a gentle slope to the eastward until it attains an altitude of about 30 to 40 feet.

Resting upon an eroded surface of sandstone, the 'ground

---

[1] *Trans. Manchester Geol. Soc.*, 1889.

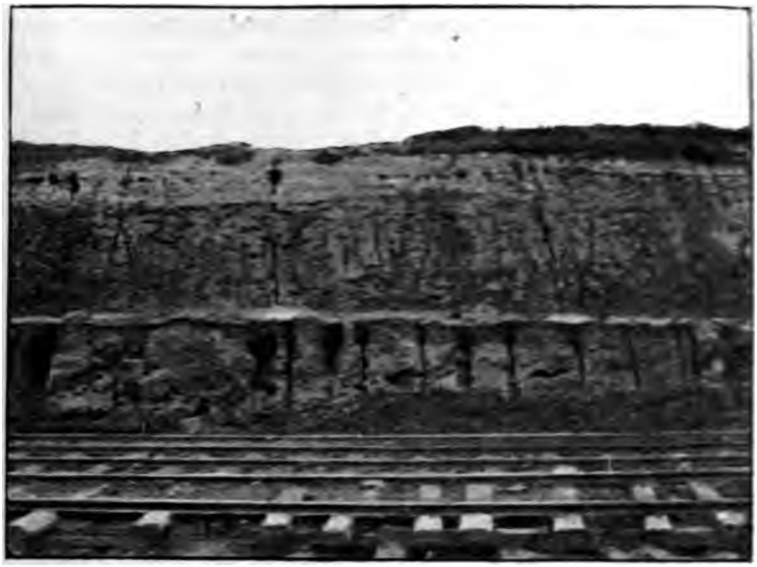


Fig. 50.—Boulder Clay, crushed compact. Ship Canal, Malley Common section.

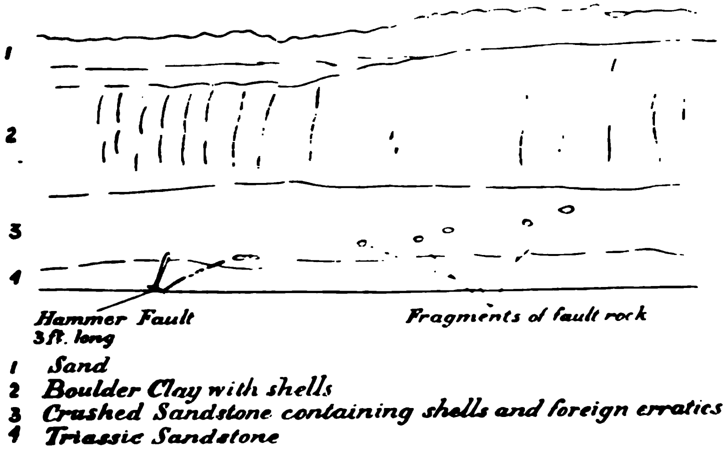

1
2
3
4
Hammer Fault
3 ft. long
Fragments of fault rock
1 Sand
2 Boulder Clay with shells
3 Crushed Sandstone containing shells and foreign erratics
4 Triassic Sandstone

Fig. 51.—Section on north bank of Ship Canal at Malley Common.

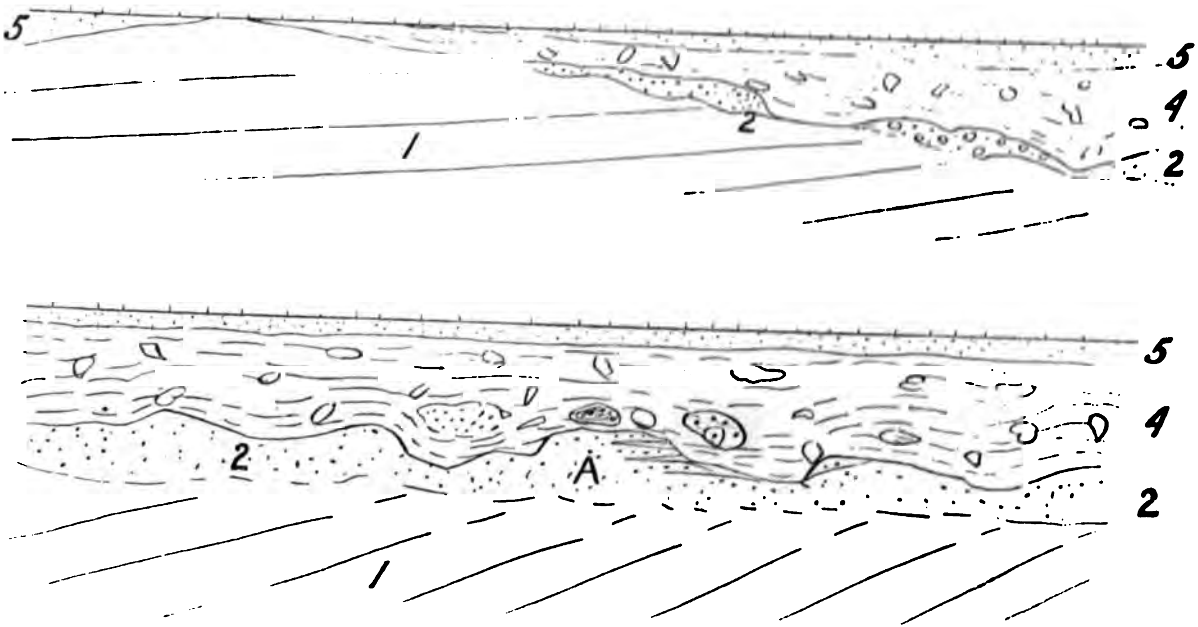


Fig. 52.—Section on the Manchester Ship Canal, 200 yards west of Bell House Lane Bridge.

moraine' comes on. This deposit is here about 4 feet in thickness, and contains irregular seams and pockets of gravel containing foreign stones, such as granites and lake district lavas.

The ground moraine terminates upward in a sharp and clear line, marking it off from a deposit of tough boulder clay containing many scratched stones and an unusual abundance of shell fragments.

I happened to observe in the underlying sandstone a small fault, characterised, as is usual in the red Triassic rocks, by the occurrence of a zone of bleached rock, which also exhibited the usual slickensiding.

This directed my attention to the overlying ground moraine, and in that I found fragments of the slickenside trailing away from the fault *in an easterly direction* for fully 50 yards, and rising so that in a distance of 10 yards the uplift amounted to one yard. A careful search to the westward failed to reveal a piece of the fault stuff carried in that direction.

On the opposite side of the cutting, at a distance of about 70 yards, there was an exposure of ground moraine which yielded foreign stones in abundance, and also fragments of marine shells, including dentalium sp. There was here, too, proof furnished of the immediately local origin of the ground moraine in the fact that it was crowded with small spherical concretions precisely similar to those found in the underlying sandstone. I may remark that Mr. H. C. Beasley, who is one of the best authorities on the Triassic rocks of England, informs me that he is not acquainted with any other outcrop of Trias in which similar concretions are to be seen. About 200 yards to the eastward of this section a bed of finely bedded sandstone presented its edges at a low angle towards the westward, and the stratification showed signs of disturbance by some force acting from the westward, which had pushed the beds into a low arch. This disturbance was not traceable for more than three or four feet down.

Several very good illustrations of ground moraine, bearing evidence of local derivation, and giving occasional indications of the direction of ice-movement, are visible in the cuttings near Acton Grange.

Fig. 52 is on the south bank of the canal, about 200 yards to the westward of Bell House Lane Bridge.

1. Triassic sandstone, merging into 2. Sandy ground moraine. 3. Very gravelly ground moraine. 4. Boulder clay. 5. Sand and vegetable mould.

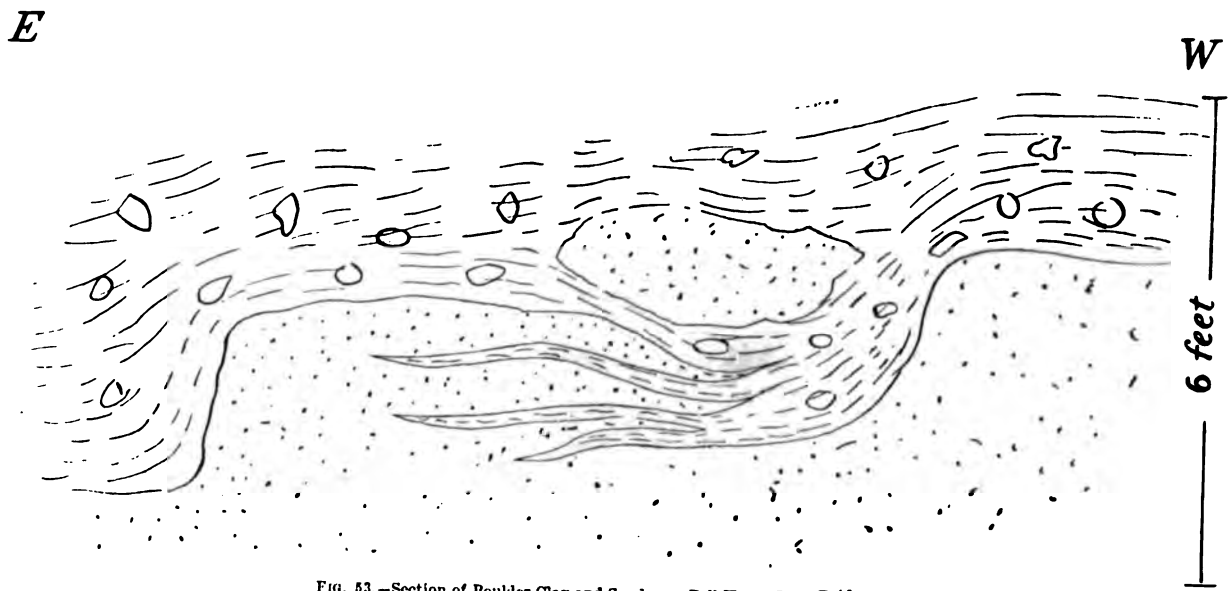


Fig. 53.—Section of Boulder Clay and Sand near Bell House Lane Bridge.

The boulder clay in this section contained fragments of shells and included several patches of sand of the same nature as the ground moraine. The ground moraine consisted of sand with some gravelly patches (containing foreign stone) and isolated masses of boulder clay. The junction of boulder clay and ground moraine at the point marked A is of particular interest, and I give an enlargement of it in fig. 53.

There are other sections on the Ship Canal, which may conveniently be mentioned here, and though they do not all show the ground moraine, it is well to introduce them in order that an idea may be gained of the persistence, under varying aspects, of evidences of ice-erosion at intervals through the entire length of the great excavation.

At Pool Hall Bay, near Ellesmere, on the south-eastern slope of a sandstone hill, and within a quarter of a mile of a scratched surface, I observed this section.

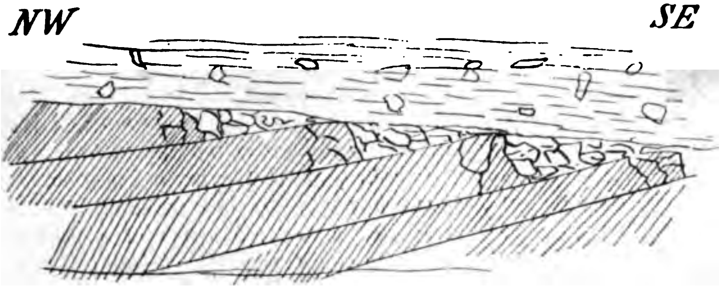


FIG. 54.—Section at Pool Hall, near Ellesmere Port.

Here the boulder clay is seen resting on Triassic sandstone (pebble beds) which dip at a low angle to the westward. There is no ground moraine in the sense in which I have hitherto used it, but in the angles between the basset-edges there is a coarse rubble of sandstone blocks, which seem rather to have been produced by a drag operating to widen the joints rather than by any actual crushing.

At the old lock-house on Stickins Island, below Barton, there is an exposure which is chiefly interesting for the evidence which it furnishes of somewhat violent treatment of the boulder clay, or, as those who subdivide that deposit would doubtless say, of *three distinct boulder clays.*

The description of these beds in ascending order is:—

1. Pale yellow-red, false-bedded sand with seams of gravel and of coal fragments. Particles of shell rarely occur.

2. Dark sepia-coloured clay with very few stones. At the point A the clay is distinctly laminated parallel to the under surface, and *the stratification planes are highly polished as if by slickensiding.*

3. Reddish-brown, very sandy clay containing many rounded stones.

4. Very hard blue to brown or sepia clay, with many scratched stones, especially at the base, where they are of large size.

One of the most interesting sections along the whole line is one which I had the pleasure of showing to Dr. Crosskey, during a late visit to the district. It extends for about a quarter of a mile on either side of Bob's Bridge, near Moore, and displays the most diversified series of beds that I have seen in any glacial section in the neighbourhood. I may mention that the measurements are close approximations to accuracy, the horizontals being obtained by pacing, checked by the lengths of the rails on the temporary railway.

The cuttings near Moore exhibit what is probably the most important section of the glacial deposits to be met with on the Ship Canal. A very great variety of beds is exposed, and some of the physical features are without a parallel in my experience.

Beginning at the westward side, there is a mass of boulder clay to be seen abutting against a very steep face of a boss of sandstone, which dips in a general easterly direction. The superficial portion of the sandstone is in a disintegrated condition, suggestive of crushing, and the boulder clay surmounts the top of the boss.

The middle of the sandstone mass is traversed by a deep gully about 15 feet deep by 30 feet wide, which is filled with stratified sands and gravels containing many large erratics as well as blocks of the sandstone. These beds do not, so far as I can ascertain, contain any shells or shell fragments, though in the bed of boulder clay they are fairly numerous. On the eastern slope of the sandstone the boulder clay does not rest directly on the bed rock, but two very remarkable beds intervene. Immediately in contact with the sandstone surface, which is quite sound and strong, there is an extensive deposit consisting of red sand, intermingled with a multitude of stones of various sizes from that of a walnut to that of a man's head. These

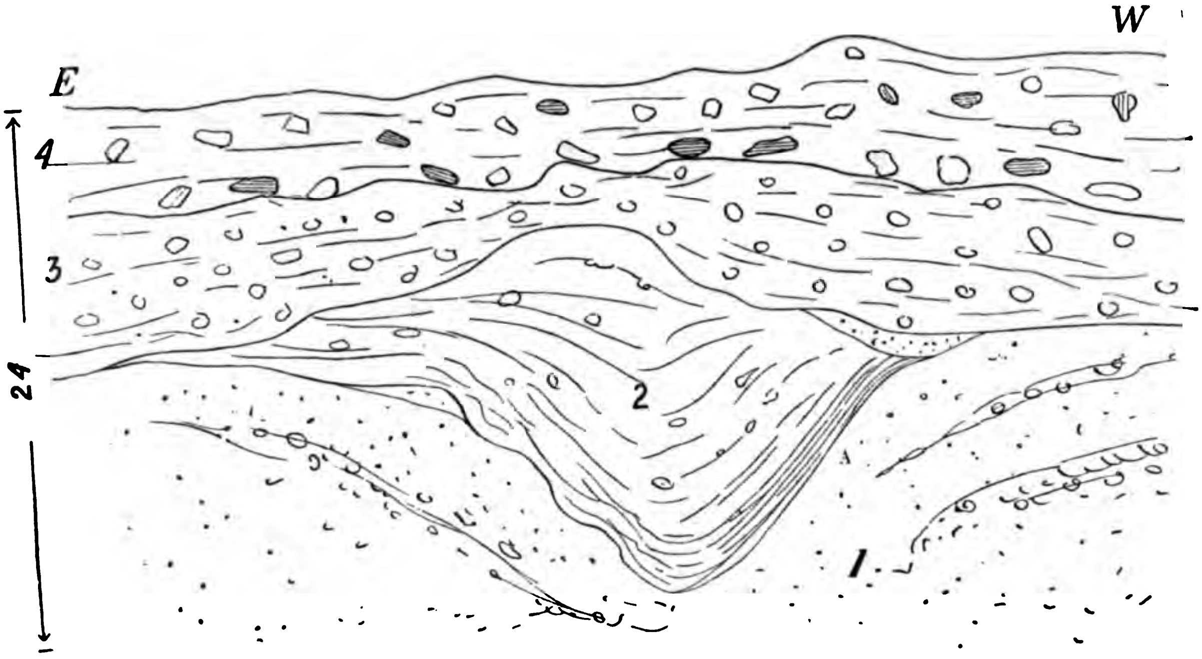


FIG. 55.—Section at Old-Lock house on Stickins Island, below Barton.

[illegible] are partly water-worn, but a large proportion consist of ro [illegible] [illegible] of the adjacent sandstone. There [illegible] appearance of stratification, but the upper and lower s are nearly parallel, and the dip of the bed is about 15° [illegible]

[illegible] the gravelly bed there appears a mass of fine red [illegible] one or two thin gravelly seams, which confo ity to the [illegible] bed, and has a thickness of not less than 1 The next in succession is a bed of rather soft boulder clay, no true appearance of stratification and occasional lenti sand and gravel. The easterly dip is maintained, though [illegible] angle, so that the clay thickens somewhat to th west.

Above the boulder clay comes a great series of bright [illegible] gravel, sands with shell fragments, and those masses of clay to which the name of "clay-galls" is given.

In an easterly direction this sandy series ends against a [illegible] face of sandstone, and at the top a long wedge of boulder clay, containing shell fragments, abuts by the bro of the wedge against the top of the sandstone, into whic [illegible] and pressed in [illegible].

The section appears to me to be capable of explanation o supposition that a mass of land-ice advanced from the wes and that the boulder ground moraine was deposited again this side of sandstone, where the rock on the weather sid [illegible] and crushed by the impact of the ice. Upon the w side of the sandstone [illegible] the escape of water from the m of ice would, I conceive, produce such a steep bank of gravel sandy material as I have described. The onward movem the ice-mass would spread a layer of boulder clay over thes and during a subsequent stage, sub-glacial streams or water f from a melting front would lay down the shelly sands des over which finally the ice dragged another layer of boulde and crushed the face of sandstone against which it was th

The most significant fact in this description is that sands or gravels are in contact with the sandstone, the ro plays a water-worn surface, but where on the weather s sandstone masses the boulder clay is in contact, the rock [illegible] not water-worn but *crushed in situ*.

The boulder clay has yielded to me at this place the fol shells, some of them in an approximately perfect conditio the great majority represented only by small fragments ver

cult of determination:—Turritella communis, Scalaria sp., Buccinum undatum, Nassa reticulata, Purpura lapillus, Fusus antiquus, F. gracilis (?), F. scalariformis, Murex erinaceus, Pecten opercularis, Pinna (?), Cardium edule, C. rusticum, C. echinatum, Cyprina Islandica, Astarte borealis, Venus sp., Psammobia ferroënsis, Lucina borealis, Mya truncata, Tellina balthica, Balanus sp., Salicornaria sinuosa.[1]

The data furnished by the sections which I have described will enable us to discuss the question of the mode of production of the ground moraine and its relation in point of age and origin to the boulder-clay; and, at the same time, we may gather up all the evidence yielded by the sub-glacial surfaces as bearing upon the antagonistic views of glaciation, the floating-ice and the land-ice hypotheses.

The wide prevalence of a deposit of unstratified sandy material intervening between the boulder clay and the solid rocks can be only explained, as Mr. Mellard Reade has well pointed out, by supposing it to be the product of a great sheet of land-ice. The immediately local origin of the materials and the constant easterly or south-easterly drag, agreeing, as it does, with all the indications yielded by the transport of local boulders, the orientation of boulders, the direction of the scratches upon their upper surfaces, and the rock-striation constitutes such a mass of testimony bearing in one unvarying direction, that I think it may be safely regarded as proof that a general agent was at work which disregarded all the minor details of physiography.

Its relation, in point of age and origin, to the boulder clay appears to me to be equally evident. The discovery that foreign stones are embedded in the unstratified ground moraine (see the Malley Common section) proves that foreign sources of supply were open to the abrading agent; and, indeed, it is difficult to imagine how an ice-sheet of such dimensions could possibly invade Lancashire without bringing foreign stones with it.

The ground moraine, then, contains foreign stones and shells beside patches of hard stony till. The stones are of the same kind as those in the overlying boulder clay. What, then, is the difference between the two deposits? It seems to me that the sole difference is in the proportion of foreign to local material.

---

[1] It is important to note that shells, or fragments of shells, occur in every division of the glacial series in Lancashire and Cheshire whether it be ground moraine, lower boulder clay middle sand or upper boulder clay.

The unreality of this distinction is very obvious, and the explanation most in accordance with the facts appears to be that the two deposits had a common origin; but that whereas the boulder clay consisted of far-travelled material, which was dragged along by the ice-sheet, the ground moraine was the product of the sheet when by some variation of pressure it eroded down to the solid rocks of the country. This latter process may conceivably have happened at any time during the occupation of the country by ice, but I think that the greater portion of the ground moraine was produced during the first advance of the ice.

Denudation of a bed of boulder clay after its first production was no doubt of frequent occurrence, and hence the appearance presented by the Stickins Island section, where three deposits of boulder clay of different character and contents are to be seen in one vertical section.

In the cuttings of the Manchester Ship Canal more than nine-tenths (linear) of the junctions between the boulder clay with the underlying rock showed evidence of ice-work, and from what I have seen on railway and other cuttings in Lancashire and Cheshire, I am convinced that this is a by no means excessive estimate of the proportions generally prevailing. This estimate is in a large degree borne out by the evidence of local erosion yielded by the relation which exists between the character of the boulder clay and that of the rocks in the district, as well as by that even more obvious evidence of the transport and scratching of local stones.

So vast an amount of work and such constancy of direction cannot I believe be attributed to ice-berg or floe action.

Many writers have commented on the difficulty of accounting for the extremely hard till on any other hypothesis than that of its accumulation under the pressure of an immense thickness of ice. Now, in many of the Ship Canal cuttings the till is of a hardness not to be surpassed anywhere.

In the Eastham cuttings explosives have to be employed to loosen it, and it sometimes happens that a mass will get jammed in the bucket of the steam-navvy. When this occurs it is necessary to cut it out with sledge-hammers and chisels. The stratification which is occasionally to be seen in some boulder clays may be attributed to one of two causes, both, I think, operating at times. Soft clays may not improbably owe their stratification to deposition in an unusually wet state, and this would also account for an occasional rarity of stones in these

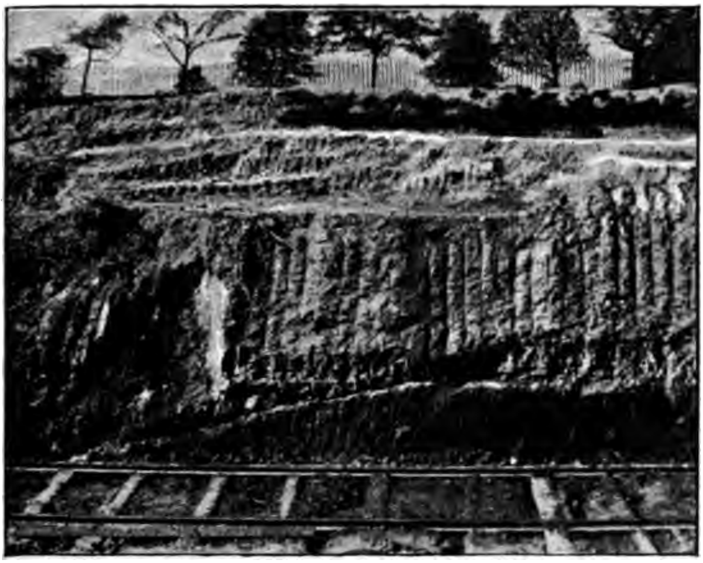


Fig. 56. Grit forming Base of Permian Marl. The surface is ice-scratched.

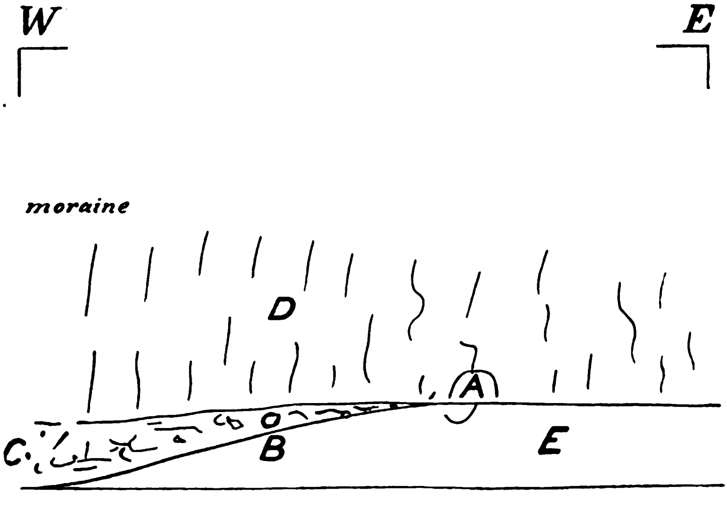


Fig. 57.—Section of Railway Cutting near Fallowfield, Manchester.

varieties; and, indeed, I am strongly of opinion that some of the clay, such as that at Heaton Mersey, near Stockport, was deposited in water by ordinary sedimentation, though I do not thereby admit or suggest that it need necessarily have been sub-aerial water.

Another and wholly different species of lamination is that which is seen in the very hard clays accompanied, as at Stickins Island, by slickensided surfaces. This form, I think, is clearly due to the *shearing action* of a great mass of ice gliding overhead.

The foregoing illustration (fig. 56) shows the junction of the drift with the Permian rocks in a railway cutting near Fallowfield, Manchester.

The bed E, of which the dip slope is seen on the left, is a bed of strong grit containing some large pebbles, which forms the base in the Manchester district of the Permian marls. At the point A, a planed surface was exposed, showing striæ running from N. 65 W. to S. 65° E.

Resting upon the dip slope, which is so clearly marked, was a mass of marl C, kneaded up and containing numerous pebbles and boulders of rocks foreign to the district; e.g. the stone marked B is a block of Andesitic lava clearly derived from the Borrowdale series of the Lake District. The basal portion of the boulder clay D, for a long distance to the eastward of the point A, contains masses of marl, including some well-striated examples of the septaria which occur in that formation.

It is important to observe that the striæ agree in direction with those observed on the upper surfaces of the boulders in the same sections, and also with the carry of the local stones.

II

THE GLACIAL PHENOMENA OF THE LANCASHIRE AND CHESHIRE AREA CONSIDERED WITH REFERENCE TO THE SUPPOSED THREE-FOLD DIVISION OF THE DRIFT.

On this subject I shall speak mainly from experience drawn from the tract of country bounded on the north by a line drawn from the neighbourhood of Lancaster to Burnley, on the east by the Pennine Chain, and on the west by the uplands running up to the Welsh mountains. . . . Throughout the area as thus defined, deposits of clay and sand with or without scratched boulders are thickly strewn, except in the hilly districts where they occur only sporadically, if at all.

Ice-scratched surfaces are so rare as to call for especial note whenever they are brought to light, a fact which is undoubtedly to be attributed to the nature of the receptive surface. The solid rocks of the district are for the most part soft sandstones and marls, materials which were rather crushed than scratched when the great glacier passed over. The glacial deposits have been classified by Prof. E. Hull [1] into three groups, viz.:—

1. Lower boulder clay.
2. Middle sands and gravels.
3. Upper boulder clay.

This classification has been adopted by the officers of H.M.'s Geol. Survey, and by many independent geologists, though not a few of the closest students of the glaciation of the district have found themselves opposed to it. The subdivision into three groups has been brought into relation with the prevailing theories, viz. (1) that the British glacial deposits were *not* the products of one continuous glacial epoch, but were produced during two or more periods separated by intervals during which the climate mitigated its rigours and permitted the withdrawal of glaciers back to the mountain valleys and the influx of animals and plants both terrestrial and marine suited to a temperate or cold temperate habitat; and (2) that the relative positions of land and sea were *not* in the main as we find them now, but that there were great fluctuations of level.

The lower and upper boulder clays are assigned respectively to the periods of major and minor glaciation, while the middle sands are allocated to the inter-glacial period.

From this classification, and from the theoretical conclusions drawn from it, I alike dissent.

Such a classification of the deposits may be supported by three varieties of evidence—stratigraphical, lithological, and valveontological.

The *stratigraphical* evidence cannot be regarded as conclusive because of its extreme flexibility. For example, suppose in a given section, a mass of sand to be seen interposed between two beds of clay, it will be claimed that the series is complete. Suppose a bed of sand to repose *upon* clay, here, it will be said, that the upper clay has been removed by denudation. Should the deposits above the solid rock consist of sand covered by clay, it will be interpreted to mean that the lower boulder clay had been removed by denudation before the deposition of the sand.

---

[1] *Proc. Man. Lit. and Phil. Soc.*, 1865, p. 449.

Such arguments as these are at one and the same time unanswerable and quite inconclusive.

The *lithological* character might be expected to yield a safer guide, and, in truth, it is of crucial importance to determine whether or not there is a radical and essential difference between the lower boulder clay and the upper. It is indeed a vital necessity to the tripartite scheme that there should be some intrinsic features, either of composition or of contents, by which the clays may be differentiated.

These two deposits of clay are, however, indistinguishable. It has been supposed that the lower boulder clay is the harder and more stony of the two; but against this I may cite as one among the many cases which have come under my own observation, an instance at Heaton Mersey. Here a bed of clay rests directly upon the Triassic sandstone, while it is overlaid by typical 'middle sands.' The clay is through almost its entire thickness finely laminated and crumpled; singularly few stones are embedded in it; it is very soft and contains many shell fragments.

On the other hand, a thick bed of clay which rests upon the 'middle sands' near at hand, is hard and tough and contains many well-scratched stones. One such example as this is sufficient to dispose of any lithological test for lower boulder clay; and my own observations show that the beds vary between the uttermost extremes within a very short distance.

Moreover, whenever sections of any considerable length are opened, they rarely fail to exhibit lenticular patches of sand and gravel interposed between beds of boulder clay; and in many cases there are two or more beds of sand in one vertical. These beds of sand occasionally attain very large dimensions; for example, in the neighbourhood of Preston they are traceable for several miles, and again in the neighbourhood of Stockport. It must be noted, however, that the outcrops are singularly intermittent, and that the sands vanish and reappear in a very erratic manner, while partings of stony clay occur from time to time.

It appears to me that the occurrence of two or several superimposed beds of clay, with partings of sand and gravel of greater or lesser extent, do not mark actual subdivisions of the glacial epoch, but *local* phases of deposition, so that sands might be deposited side by side with (so-called) 'upper' or 'lower' boulder clay. In other words, I think that the varieties in the deposits are a testimony to differences *not* of age, but solely of conditions; and that this is the explanation of the fact that wherever, from the physiographical features of the country, the conditions were most likely to have varied frequently, *there* we find the greatest number of alternations among the beds and the most rapid changes. The theory which attributes all our west-country glacial deposits to the action of confluent glaciers with their necessary accompaniments of sub-glacial streams, and extra- and inter-morainic lakes, appears to me capable of explaining all the phenomena hitherto observed.[1]

While the stratification is of so inconstant a character as to invalidate the hypothesis that there is any definite bed of sand or other material representing an inter-glacial period in the Lancashire and Cheshire area, the *palæontological* evidence is equally unsatisfactory.

I shall discuss this evidence in a subsequent section; but I may state at this point the conclusions to which I have been led by a critical examination of all the lists of the fauna of the beds published up to this date (1890).

The fauna of the 'middle sands and gravels' yields no support to the theory of an inter-glacial period on the western side of England. Indeed, *if reliance is to be placed upon the shells*, there is ample justification for the statement that the sandy deposits which have been called 'inter-glacial' were laid down under conditions of greater, rather than lesser, severity than the boulder clays with which they are associated, inasmuch as they contain a fauna which, in its entirety, is decidedly of a more boreal type than that found in the boulder clays.

III

LOCAL DRIFTS AND THEIR JUNCTION WITH THE GENERAL GLACIAL DRIFT

The study of the phenomena displayed by those glacial frontiers or border-lands where the great northern drift met with and overpowered the local ice is of high importance in this inquiry. In this study I have kept steadily in view the necessity for discriminating between the effects of land and floating ice respectively. In the case of the former I should expect to find abrupt transitions in the character of the deposits and their contents, whether traced horizontally or vertically, while in the latter case it is reasonable to suppose that the transition would be a gradual or even an imperceptible one, as the deposits would be the products of floating ice from several sources, whose predominance would be variable, and thus there would be a constant intermingling.

---

[1] It may here be noted that Professor Kendall's conclusions, as given in the foregoing paragraph, are identical with those held and announced by Professor Carvill Lewis at the meetings of the British Association in Birmingham, September 1886, and in Manchester, September 1887.– J. F. L.

The districts where these features may be studied may be conveniently divided into five well-defined regions.

1. The south Cumbrian or Barrow region, where the granite-bearing drift from the north marches with the local ice from the Windermere and Honister district.

2. The Ribblesdale region, where the conjoint streams from the northern and southern portions of the Lake District met the Yorkshire Fells.

3. The west and north-west margin of Wales, where the native drift was opposed by the northern drift.

4. The east and north-east margin of Wales, where similar conditions may be observed.

5. The Isle of Man, where the relations of the native to the foreign drift can be studied better than in any place with which I am acquainted.

(Many references to these various areas will be found in Prof. Lewis' 'Field Notes.' I extract from Mr. Kendall's MSS. his account of the Ribblesdale region, which he has personally examined, and which Prof. Lewis also traversed. A summary of the results of Mr. Kendall's researches in the Isle of Man will also subsequently be given.)

The Ribblesdale Region.—The portion of the valley of the Ribble about Whalley, in Lancashire, is interesting for several reasons. I was induced to study it for the purpose of deciding a question of vital importance in its bearing upon the rival theories of glaciation.

The Ribble flows for the greater part of its course down to Whalley through a mountain limestone country, and Mr. Tiddeman, in his paper on the 'Evidence for an Ice-sheet in North Lancashire,' [1] which deserves to take rank as a classic, has shown that the ice-movement throughout the district was in the main from north to south, and that an abrading, crushing, and overturning agency sufficiently powerful to ignore the hills and valleys which lay across its path, was in operation, and he attributes the whole of the glacial pheuomena observed there to an ice-sheet.

---

[1] *Quart. Jour. Geol. Soc.* xxviii.

My own observations on the southern part of the district are as follows:—At Clitheroe I found a finely striated and moutonnée surface in a quarry near the top of a limestone hill at Bellman Park. The striæ took the direction east-north-east to west-south-west, the boulders in the overlying boulder clay were of very dark limestone, *and all that I observed lay with their long axes parallel to the scratches.*

The valley from this point downward is broad and open, being bounded on the north by hills running down from the Fells of the West Riding, while on the south the great Pendle Range runs like a wall. At Whalley a breach in the Pendle Range brings in the Lancashire Calder from the Burnley district, and the south-westerly continuation of Pendle forms the plexus of hills which rise to their highest at Knab, about half a mile from the Calder, whence they dwindle away by a series of lessening undulations until they fall into the plain near Preston. On the right bank of the Ribble the ground is high as far as Longridge.

Above Whalley, in the gorge of the Calder, a threefold arrangement of the drift is visible at one place, viz. (in descending order):—

1. Sand, with laminæ of clay and coal horizontally bedded, but rather inconstant. No foreign stones noted.

2. Sticky boulder clay, containing many well-scratched limestones and occasional grits and carboniferous shales. The long axes of the stones lie north and south magnetic (about N. 19° W. true).

3. Sand, containing two seams of clay, each about a foot thick, containing many small stones. The sand is minutely false-bedded towards the north-west or north. Stones were very scarce in this sand, but fragments of coal were disposed in thin seams.

In this pit the Geological Survey officers found 'obscure fragments of marine shells,' but no foreign stones. I could not confirm the presence of shell fragments, but among the very few stones present I detected two undoubted Lake District lavas.

My next section was in a brickworks just beside the Whalley Railway station, and there Lake District and Scottish rocks occurred in profusion, *but no limestones*; however, an examination of the faces of the workings revealed the existence, in a great thickness of soft sepia-coloured clay with exotic boulders, of a thin band of red clay about six inches thick, which I was informed by the workmen was always cast aside as unfit for use on account of the presence in it of limestone boulders. It was further stated that limestones occurred in this bed alone, and that none were found in the main mass. My informant also said that below the clay came a bed of sand 4 to 5 feet thick, resting on 'marl,' which he explained to be clay that would effervesce with acid. The lowermost bed in the section previously described would appear to be above the top of this pit.

It is clear that there is here a definite junction of local with foreign drift in vertical succession with little or no intermingling. The whole series, if joined into one sequence, would give the following as the succession of beds:—

On the Calder	Sand, 12 feet	Probably foreign
	Clay, 50 „	Local
	Sand, 25 „	Foreign
In the Brick pit	Clay	Foreign
	Red clay	Local
	Clay	Foreign
	Red Clay	Local
	Clay	Foreign
	Sand	(?)
	'Marl'	Local

The horizontal distribution could not be made out, but northward, at Mitton Bridge, there is a splendid section, about 80 feet high, showing sandy boulder clay, containing multitudes of huge limestone boulders with a few sandstones and grits, but no exotics. On the Calder, near its junction with the Ribble, there were many fine boulders of Eskdale and other granites, but no limestones, so that between there and Whalley brickworks on the one hand, and Mitton Bridge on the other, the battle was fought out.

I endeavoured to trace the foreign stones over the hills culminating in the Knab, and successfully. From Langho station scattered relics were traceable of a drift containing limestones from Ribblesdale, and various foreign rocks, such as Buttermere syenite (granophyre), at intervals up over the hillside and on into the very heart of the hills.

Taking now a comprehensive view of these facts, and combining them with others that have been recorded, we may suppose that the boundary of the granite-bearing drift has crossed Morecambe Bay (the precise point where it strikes the eastern side of the bay has not been ascertained); thence it passed on, by way of, and over, Longridge Fell, where I found foreign stones on both flanks and over the top. In the stone quarries on Tootle Heights, Longridge Fell, I found two well-scratched surfaces (one overlaid by sandy drift containing about 1 per cent. of exotic rocks, including an Eskdale granite), the striæ on which run from N. 52° W. and N. 64° W. respectively. From Longridge onward I am unable to define the limits of the northern drift, but it was clearly pressed up Ribblesdale to the junction of the Ribble and the Calder; here it turned in an easterly direction, and passed up the gorge of the Calder near Whalley, and perhaps continued to follow that river towards its source. On the right, it covered the Knab Range and all southward. There are indications that the northern drift maintained its continuity in this direction, and at Burnley many granite and other boulders belonging to regions to the north-west have been found.

IV

THE CHARACTERISTIC ERRATIC BLOCKS OF WEST LANCASHIRE AND CHESHIRE

The true foreign erratic blocks of the north-west plain—with the exception of some dozen or so of individual boulders exclusively derived from the country bordering on the northern half of the Irish Sea—are the following.

Granites from each of the great intrusive masses of the south-west of Scotland, Criffel, and Loch Doon are represented. The granites of Eskdale and Buttermere are extremely numerous and the volcanic rocks of the English Lake District make up the majority of the foreigners. With respect to the Shap granite, only a feeble trail can be followed down the valley of the Lune by West Bank to Lancaster, and thence onward as far as Longridge, but to the southward of that place the trace It has indeed been stated[1] that the Shap granite is a charact boulder of the Manchester district, but only one doubtful men has as yet been recorded.

Ireland appears to be undoubtedly represented by flints, apparently water-worn, and there is a record also o chalk, which, perhaps like the flints, came ultimately from A though in the case of these two rocks it is necessary to with some caution, for the chalk is a very widesprea mation, and we have no means of ascertaining even its p extension eastward of the Antrim cliffs; still less can we sa much of the bed of the Irish Sea was occupied by it i glacial times. The same may be said of the Liassic fossils very sparingly in Lancashire; but in this case there is a f ground for caution against hasty conclusions in the fac Liassic rocks containing Gryphæa incurva (the only Lias found in Lancashire) are known to exist in the vicinity of C and may not improbably range westward towards their Iris crop.

These are the foreign stones which *do* occur in the cashire and Cheshire drift, but in no way inferior in pert to the present inquiry is the negative evidence.

The eastern districts of Ireland draining into the Iris contain an abundance of strongly characterised igneous amongst which I may particularise the granites of the G Wood, Newry, and the very well-known albitic-granite Mourne Mountains. None of these have ever been recorde this district.

In the Isle of Man there are two granites of very prono characteristics, a pikrite, and a boss of very remarkable q rock containing large flakes and nests of mica. Thes similarly absent from our drift.

Turning next to Wales, there is in the principality a variety of rocks which, once seen, could never be mis and I would particularly mention the Arenig felsites which been distributed broadcast by ice over North Wales. Not these has ever been discovered in Lancashire.

In any scheme which professes to explain the accumu of our glacial deposits in the sea during a period of a dee extensive submergence, we must request an explanation absence of these rocks which are so favourably situated for ice-transport.

---

[1] *British Assoc. Handbook to Manchester*, 1887.

From the foregoing considerations it will have been made clear that there has been no random dispersal of the *foreign stones*; and when we turn to the case of the local stones we shall find this even more strikingly the case.

In a communication to the Stockport Society of Naturalists[1] I stated that, where a rock of strongly marked individuality was limited to an easily defined outcrop, boulders derived from it were found to obey what I ventured to call the *law* of boulder transport for Cheshire and South Lancashire, viz., *boulders of local rocks never occur to the north or west of the parent mass.* In other words, the direction of transport is constantly from north-west to south-east.

To this 'law' I have, in my own experience, as yet found no single exception.

It is important to add that my observations entirely confirm the statement that the boulders throughout the glacial series of South Lancashire and Cheshire show no variation of character from the top to the bottom of the series.

There is also a sharp and clear definition of each area of boulder dispersal.

V

THE PENNINE WATERSHED AND ITS INFLUENCE ON BOULDER TRANSPORT

Boulders of Shap granite have been carried over the Pennine watershed into Yorkshire by tens of thousands, not by the lower pass at Stainmoor, 1,378 feet above the sea-level, but by way of the upper pass, which is much higher, and the Shap erratics have been traced there up to an altitude of 1,800 feet, or 140 feet above the highest point reached by the parent mass.[2]

On the west side of the Pennine Chain they have been carried in small numbers to the northward down the Vale of Eden as far as Penrith, while to the southward only the feeble trail already mentioned can be traced, viâ West Bank and Lancaster, as far as Longridge.

[[1] *Trans.*, 1890.]

[2] J. Gunn, *Geol. Mag.*, 1879.

This remarkable distribution appears to me to point very clearly to the action of land-ice, and the dispersal in three directions may be accounted for partly by the fact that Shap Fell was the ice-shed (which is indicated by the striæ) as it is now the watershed, and, so far as its Yorkshire distribution is concerned, by the action of a mass of land-ice from Criffel, which was driven up the Solway Firth and the Vale of Eden during the period of maximum glaciation by the congested state of the northern part of the Irish Sea.

The Pennine watershed in the country from about Skipton southward affords a most interesting glacial study. The researches of Mr. Tiddeman[1] have made us acquainted with the glaciation of the country on the western side of the Pennine Chain as far as Pendle, and he has shown that a great sheet produced by the confluence of local glaciers passed over the country from north to south sweeping irresistibly over hill and dale.

On a line stretching from Longridge Fell, viâ Whalley, up to near Burnley, by my own observations I have ascertained that the granite-bearing drift from the west obtained the mastery *at some time during the Glacial Epoch.* I am disposed to think that some portion at least of this native ice came over the Pennine watershed, though it may have simply embayed it, aided, as it would be, by the great natural barrier of the Pendle Range. Suppose, however, that instead of regarding the granite-bearing drift as borne by land-ice, we call in the aid of the floating ice.

How will that bear examination? Granites have been found in boulder clay in the town of Burnley,[2] but I have sought them in vain in the upper part of the valley of the Lancashire Calder at Holme, nor could I find them on the other eastern slope of the same valley at Cornholme; however, to the southward, all over the high hills round Bacup, granite and other exotics have been found in boulder clay, and on Heald Moor above Bacup at an altitude of 1,412 feet. This spot is precisely on the summit of the Pennine watershed.

If we trace the line farther south we shall find less satisfactory and less complete data, but the whole suite of Lake District rocks have been found near Rochdale at an altitude of 800 feet. From this place the line would include the high grounds above Oldham and Staleybridge. Turning to the eastern side of the watershed through the whole length of country I have defined only at one or at most two places have the foreign rocks crossed the watershed. Near Mytholmroyd, on the Yorkshire Calder, a few granite pebbles have been found in the gravels, and near the summit, on the railway between Manchester and Todmorden, a mass of boulder clay belonging to the western dispersion has been found. How can this be accounted for ?

---

[1] *Quart. Jour. Geol. Soc.* xxviii.

[2] Wilkinson, *Geologist*, vi. 192.

If the Heald Moor boulder clay be a marine deposit it points to a subsidence there (without allowing for clay being a comparatively deep-water deposit) of upwards of 1,400 feet. What prevented the flow of ice-laden currents through the broad and open Skipton valley which is 800 feet lower ? It is contrary to all experience to suppose that a marine current could come to a dead stop, so that the question, where did it go to ? requires an answer. Again, it would be very unreasonable to suppose that there would be no reciprocal distribution of boulders, the Yorkshire oolites and chalk coming westward with even a few Scandinavian rocks, such as the famous *Rhomben porphyr*, in exchange for Lake District and South Scottish rocks. Yet we have no evidence that these things have happened.

VI

VERTICAL DISTRIBUTION OF BOULDERS RELATIVELY TO THE PARENT MASS

In every great area of glaciation with which I am acquainted boulders are found uplifted above the outcrop of the parent rock. This may be the case when the rocks have been carried to a great distance; for example, on Moel Tryfaen the following rocks occur (the figures indicate their height above the parent source[1]): chalk flints, 850 feet; Eskdale granite, 64 feet; and on Trondeg,[2] Eskdale granite, 116 feet.

Mr. Tiddeman, in his paper on the 'Evidence for an Ice-Sheet in North Lancashire,'[3] mentions cases where the uplift has been much more considerable, and within much narrower limits of horizontal transport.

Mr. Goodchild[4] describes the dispersal of the Permian Brockram, and shows that it has undergone a vertical uplift of 650 feet in passing up the Vale of Eden to the Stainmoor Pass.

---

[1] Mackintosh, *Quart. Jour. Geol. Soc.*, xxxvii. 353.

[2] *Ibid.* p. 366.

[3] *Quart. Jour. Geol. Soc.* xxviii.

[4] *Ibid.* xxxi. 64.

I have found a bed of boulder clay at Apethorne Mill, Hyde, Cheshire, containing marine shells and a great abundance of boulders of Ardwick limestone considerably to the eastward, and at least 100 feet above any outcrop of the rock. These examples are all illustrative of the general proposition that boulders may occur above the parent mass, but a decisive case appears to me to be that recorded by Cumming, in his work on the Isle of Man, a case which I have personally examined. In the central part of the island, near Foxdale, there is a boss of granite, well defined in petrological character and in outcrop. Boulders of it occur plentifully on the south-western side of the mountain, South Barrule, at a distance of one and a half miles from the boss. My own investigations in the Isle of Man show that the general direction of ice-movement in that island was approximately from north-east to south-west, and though I carefully searched the drift and the beds of streams northward of Foxdale, I could find no traces of a dispersal of the granite in that direction.

Here the hypothesis of a great glacial submergence, in my opinion, receives a fatal blow. It passes credence that floating ice could persistently throughout the submergence and emergence of the land have drifted in one constant direction, affected neither by the ebb and flow currents of the tide, nor by variation of currents in consequence of winds or the extensive physiographical changes then in progress.

VII

THE CROSSING OF STRIÆ

Much has been said about the crossing of striæ, and it has been made an argument that floating and not land-ice must have produced them. This has been especially the case with regard to the striæ in South-west Lancashire and North-west Cheshire, and it may therefore be desirable that I should state the facts. These crossings are given in a diagram by Mr. Strahan,[1] and saving four of them, the variation lies between N. 15° W. and N. 60° W., a deviation of $22\frac{1}{2}^\circ$ on either side of a mean. The four exceptional readings are: (1) at Bootle,[2] N. 22° E., upon which I have no comment to make; (2) at Widnes,[1] N. 82° N.+; in this case it should be borne in mind that the scratches are found in the bed of the River Mersey, a circumstance which should prompt some caution in accepting their glacial origin, and that the river there flows through a narrow gap which could not fail to modify the flow of ice; (3) North Hill Street, Liverpool, N. 70° W., but this is only a single groove;[2] (4) Oxton, near Birkenhead, W. 30° S.,[3] which I believe to be a misprint, and should read W. 30° N., since the author, thirteen lines lower down says, 'we shall have striæ ranging from N. 15° W. to N. 45° W.'

---

[1] *Quart. Jour. Geol. Soc.* xlvii. 372.

[2] T. M. Reade, *Proc. Geol. Soc. Liverpool*, 1872 3.

The discrepant striæ are thus reduced to two sets, one of which (at Bootle) I do not attempt to explain, but the other (at Runcorn gap) is clearly explicable.

The remaining directions, ranging through 45°, are certainly no more than might be anticipated *à priori* in consequence of the varying thrusts of the several elements, English, Irish, and Scottish, the resultant of whose forces constituted for the time being the direction taken by that portion of the confluent mass which invaded Lancashire. To expect that the striæ would exhibit an unvarying parallelism is to disregard the facts connected with glacier motion.

I claim, however, that the *general* parallelism in South-west Lancashire and North-west Cheshire is so complete as to exclude the possibility of its having been effected by floating ice.

The scratches which floating ice could inscribe upon a submerged rock surface would necessarily be irregular. A mass of ice driven forward under the propulsion of a current or of the wind, grounding upon a rocky shore, and pressing over it, might produce by means of rocky fragments embedded in its base, a series of scratches at first running truly in the direction of its drift; but as the berg lost way, they would tend to become irregular, and finally the ice-mass would be fairly aground. The motive power, however, would continue to operate and swing it this way and that, and it might possibly even be twisted afloat again. During the swinging of the berg stratches of fantastic irregularity could scarcely fail to be produced. . . . When I became acquainted with Professor Lewis he informed me that it was just such an irregularity in the striæ which first suggeste his mind the idea of iceberg erosion of the rock surfaces in e morainic lakes.

---

[1] *Geol. Survey Mem. South-West Lancashire*, 1876.

[2] *Brit. Assoc. Report*, 1870.

[3] Mackintosh, *Quart. Jour. Geol. Soc.* xxxiii. 736.

THE DISCORDANCE BETWEEN THE DIRECTIONS OF THE SEV SETS OF STRIÆ TO BE SEEN ON THE BOULDERS OF L CASHIRE AND CHESHIRE

Another point to be observed is the directions of the se sets of striæ, which may frequently be seen upon boulders.

These are usually approximately parallel to the long whether they occur upon the upper or the lower surface boulder; but in all the cases that have come under my pers observation, there is a diametric discordance of *direction* bet them – i.e. while the striæ upon the under surface have been duced from, say, the south-east, those upon the upper su will have been produced from the north-west. The writin Professor A. Geikie and the late Hugh Miller have familia geologists with 'striated pavements'—that is to say, 'a horiz surface or level of till where all the prominent boulders stones have not only their original and independent striæ where they have subsequently suffered a new striation whi parallel and persistent across them all.' [1]

The observations which I have made convince me that n every large boulder in Lancashire and Cheshire has the ch teristic features of a veritable 'striated pavement.'

Before the significance of these facts occurred to me I desc a large boulder found in Manchester,[2] and showed tha noticing the 'lee-side' of prominences upon its upper and l surfaces it could be determined that the striæ on the under had been inflicted from the south-east, while those on the had their origin at the opposite end of the boulder.[3] I forn attributed this discordance to the stone having been turned during transit after the first set was inflicted.

From the fact, however, that I found the upper surfac boulders to be similarly striated *as a general rule*, I was l conclude that the chance turning of boulders would not acc for the phenomena, but that some general cause must ope more especially as the turning would need to have been *end*

---

[1] *Trans. Geol. Soc., Glasgow*, vol. i. part ii.

[2] *Trans. Manch. Geol. Soc.* vol. xx. part vi.

[3] It may be well to remark that the striæ on the under side were e tional, as being not strictly in the direction of the longest axis.

A remarkable group of boulders at Levenshulme furnished the clue, and the explanation I would offer is, that the scratches on the under surface were produced by the boulder, embedded in a moving mass of ice, having been dragged over a rocky bed, and hence all the striæ will originate at the front end of the boulder. When the boulder was torn out of the ice by friction with the ground, the glacier movement would continue, and the boulder will now form a portion of the floor, and the boulder-laden ice will follow on so as to scratch the upper surface from the hinder end. In other words, while the differential motion was between the boulder and the ground, the under surface would be scratched from front to rear, but when the ice lost its grip upon the boulder the motion was between the stone-laden ice and the boulder, and therefore the upper surface would now be scratched from rear to front.

It would follow from this hypothesis that the striæ upon the under surface of the stone, being always parallel to the direction of ice-flow (which determines the position of the longest axis), would all be in one direction, and since they would be, in most cases, the products of a long journey, they should be in general strong, and persistent in direction, and the lower surface from much attrition should be ground to a tolerably true plane.

The upper surface would, on the other hand, be less regularly flattened, and though it would always present a set of striæ parallel to the longest axis, yet the varying movements of the ice-flow might sculpture other marks upon the block.

I do not doubt but that these features have been noticed by other geologists, though I can find no specific allusion to them except in the case of striated pavements.

VIII

THE FAUNA OF THE DRIFT IN THE WESTERN AREA OF ENGLAND AND WALES

With respect to the fauna of the drift in the western area of England and Wales, four principal points have to be considered, viz. the indications they afford regarding (1) the depth of water; (2) the temperature; (3) the relations of the character of the deposit to the known predilections of the animals whose remains are found embedded therein; and (4) the physical condition of the shells. . . . .

No palæontological division can be established between the beds; e.g. I have revised the lists of the shells found in the West Anglia deposits by Mr. Shone,[1] and added the list Miss Ffarington has published of those found in her pit at Leyland, and find that the distribution of Boreal, now British, species is as follows:— Lower boulder clay, 5; middle sands, 13; and upper boulder clay, 7.

This distribution entirely disposes of the 'middle sands' as a palæontological division, at least in East Anglia. . . .

1. *With regard to the depth of the water.* With a change of level of the country from one of slightly greater elevation than the present altitude to 2,000 feet, and a subsequent recovery to the present position, we should expect to find it evidenced by numerous beach deposits up to the 2,000 feet contour, which would have been beached twice, and by deep-water deposits in the low grounds. . . . But in the drift beds there is an intermingling of forms characteristic of different depths of water, and a significant absence of really deep-water forms such as would have found their way into the area had a depth of 300 fathoms prevailed, or even had the depth of 230 fathoms held to be proved by the Moel Tryfaen deposits been an actuality. . . . We are still awaiting the discovery of some glacial shell bed in the district under discussion, which is restricted in its bathymetric range to depths *below* 25 fathoms.

Had subsidence taken place the depth of the water would have been recorded in another way. The movements would be unlike any with which we are acquainted if they were not slow and intermittent, and therefore not only well-marked beaches and seaworn cliffs and caves might be looked for, but the boring and encrusting animals which are incessantly at work on existing shore lines would leave their traces in an unequivocal fashion.

As regards barnacle-covered rock surfaces, bored rocks, as well as seaworn caves and beaches, they are non-existent, or at any rate have not been discovered in the district under examination.

There is not in all this area one single deposit displaying unmistakably the characteristics of a genuine sea-beach. No barnacle- or annelid-overgrown rock surface has ever been discovered, nor the crypts of Pholas or saxicava in any mass of rock *in situ*. Eccentrically weathered rocks at the Brimham Rocks near Keighley have been figured as glacial sea cliffs, but it has never been seriously accepted by geologists. Mr. Horace B. Woodward, in his *Geology of England and Wales*, simply says that they 'well illustrate the action of atmospheric disintegration on rocks of unequal hardness.'

---

[1] *Quart. Jour. Geol. Soc.* vol. xxxiv.

There is even more remarkable absence from our glacial deposits of barnacle-grown shells and boulders, and of boulders bored by lithodomous mollusca. Evidence of the former kind is entirely wanting so far as I can learn, but of bored boulders the following records are extant. At the Leyland gravel pit, so celebrated for its rich yield of shells, bored stones are said to be abundant, and I have myself found one there, but on inquiry of the labourers, who are instructed to preserve them, I learned that they would turn over about 300 to 400 tons of gravel to find one. Contrast this with the condition of the stones in the red crag, where of the stones the size of a man's fist one may pick up a hundred bored specimens in an hour.

In addition to the bored stones found at Leyland, there have been found in the glacial deposits of the remainder of this immense area, thousands of square miles in extent, *two* bored stones.

One of these was found in the 'upper boulder clay' at Newton by Chester.[1] In the record of this discovery it is mentioned that fragments of the saxacava which bored the crypts remained in the holes, and the following remarkable statement is made: 'the holes were not filled with the red clay in which the boulder was found, but with sand.'

This fact places it beyond question that the boring did not take place on the spot where the stone was found.

The other bored stone was found in the boulder clay at New Ferry,[2] and was strongly planed and striated in the direction of the longer axis. . . . It is admitted, however, that this stone might have been transported by ice *after* all the boring was done.

2. *With regard to temperature* the fauna is decidedly 'inconsistent' in every sense in which such a term could be applied.

Along with a considerable number of shells of northerly range, there are in every division of the series shells which fail to find a suitable habitat in latitudes so far north as Britain at the present day. *Cythere chione* does not now range to the northward of Carnarvon Bay, where it is very rare, but it is found commonly in the three divisions of the Lancashire glacials. . . .

---

[1] *Quart. Jour. Geol. Soc.* xxx. 181.

[2] *Nature*, xl. 246.

The following remarks of Dr. Gwyn Jeffreys on the former of the glacial deposits of West Cheshire are relevant to this point[1]:—

'The mixture of the northern and southern species was very noticeable, and would seem to indicate that some of the beds were *remaniés*. *Venus chione* and *Arca lactea* are peculiarly southern forms, and yet they occur with others which are only found in so-called glacial deposits. Of the latter those found in Cheshire are of Scandinavian and not truly Arctic type. On the other hand the fossils from most of the Scandinavian post-tertiary beds are peculiarly Arctic species, but do not occur in these West Anglian beds.' . . .

3. *With regard to the relation between the fauna and the character of the deposits*, there are many contrasts.

In sandy deposits there are clay-boring species; and in clays we find shells that are never found living in such a bottom. Strictly littoral, rock-haunting shells, such as *Purpura lapillus* and *Littorinea litorea*, are found in thick clays along with the comparatively deep-water *Saxicava Norvegica* and *Tapes Virginus*.

These irregular associations will of course occur at times in all deposits, owing to shells being carried by drifting sea-weeds and other means, but they have *no* regularity of association in these glacial beds.

Two or three sand beds such as those at Moel Tryfaen seem to show something like a pure Scandinavian fauna, but I do not think it can be claimed that the shells are proved to be on the spot where they lived. . . .

4. The *condition* of the West Anglian shells no less than their association is directly against the supposition that they are *in situ*. Through all this region I do not know an instance of a pair of valves found in apposition except in the bored stones at Leyland, and whole shells are extremely rare. The fragments are frequently ice-scratched, just as the boulders are, and the best-preserved shells are such as by their form are best adapted to resist crushing.

Having thus given reasons for rejecting the theory that ascribes these shell deposits to accumulation by marine agency, an explanation is proffered more in accordance with the facts.

Such an explanation adequate to account for all the peculiarities of character, association, condition, and distribution of the molluscous and other fossils is, I believe, furnished by the theory of a great system of confluent glaciers, which acquired a head in the Irish Sea sufficient to press it in over the low grounds of Lancashire and Cheshire and against the hills which bound them. Such an ice-stream flowing across the bed of the Irish Sea would pick up the shells not only of the Boreal species, which had but recently died, but also of southern species belonging to a preceding age, and embedded in the loose pleiocene deposits lying on the sea bottom. These shells being mingled in the muddy ground moraine might be transported to considerable distances, as it is admitted on all hands that the shells in the Caithness till were. They would be subjected to great pressure, and hence only those shells would survive in considerable numbers which were of a form calculated to withstand pressure. Gasteropod shells would contain the original matrix in many cases, and so would the crypts in bored stones. Being merely erratics of a particular kind they would be scratched as other erratics were.

---

[1] *Quart. Jour. Geol. Soc.* xxxiv. 395.

The Irish Sea in pre-glacial times was probably no deeper than at present, perhaps not so deep, for the land stood higher then than now, and therefore its fauna would be a shallow-water one.

The so-called 'middle sands and gravels' I regard as merely the coarser constituents of boulder clay graded out by the action of subglacial streams; hence the shells are as it were concentrated in the sands and gravels by the removal of the finer materials, and hence, also, the fact that the microzoa have been removed from their interiors by rolling over and over, and are not found in any abundance in the sands which have been sorted by too swift a current to permit such light objects to lodge. I may parenthetically remark that the frequent occurrence of coaly seams in the sands is clearly attributable to 'grading' in accordance with the very low specific gravity of coal, and the general absence of large boulders from these deposits has reference to the difficulty of transporting large masses.

The distribution of the shell-bearing drift seems to me to offer evidence of the most convincing character of the truth of the theory here brought forward.

It is a very significant fact that those districts which are on the lee side of ice-centres relatively to the great Irish Sea glacier have yielded no shelly drift even at low levels.

This is strikingly shown by the researches of Mr. J. W. E. David, who has published a description of the glacial phenomena of South Brecknockshire and East Glamorganshire.[1] The author exhibits a minute acquaintance with beds in the district, yet he is unable to record a single occurrence of shells or shell fragments. In the discussion upon the paper, Dr. Gwyn Jeffreys, who stated that he was well acquainted with the district, remarked upon the absence of shells, and added: 'In the southern counties of England there was a similar absence of so-called glacial shells.'

---

[1] *Quart. Jour. Geol. Soc.* xxxix.

Not only, however, are there no shells in the situations I have mentioned, but my researches enable me to go a step further and establish a yet more significant point. I have searched the literature of the subject and failed to discover a single case, in the area to which I have limited myself more particularly, of sea shells in a deposit unaccompanied by what for this purpose I have termed *transmarine* drift, that is, drift containing stones which must have crossed some part of the sea to reach their present positions.

I have put this generalisation to the test by examining alleged exceptions. In the compilation of a list of localities for shell-bearing drift, I found in the *Geological Survey Memoir* on the country around Burnley an account of a bed of sand ('middle sands') at Whalley, near Clitheroe, which, it was stated, contained 'obscure fragments of marine shells' along with exclusively local rocks. The nearest locality for foreign rocks being at Ribchester, about four miles distant, I recognised that this was a vital case, and investigated it, with the result that I found Lake District lavas which must have crossed Morecambe Bay—in the particular bed which yielded the fragments of shell, but, more than this, it led to the discovery of the interdigitation of local with foreign drift.

Another apparent exception was brought to my notice by the discovery of shells at Gloppa, near Oswestry. I visited the pit and again found confirmation of my generalisation. Finally, shells have been found at Halkin Mountain in Flintshire. A recent visit to this place enabled me to record the occurrence of Eskdale granite and other transmarine rocks at the very summit of the mountain in the gravel mound called 'Moel-y-Crio.'

Summary of Conclusions.—I hold that the following facts taken cumulatively constitute so weighty an objection as absolutely to forbid the supposition that the glacial deposits of Wales and the west of England are of marine origin.

1. The total absence of seaworn cliffs and of well-marked sea-beaches at high levels.

2. The entire absence of bored and barnacle-encrusted rock surfaces.

3. The practical absence of similar bored and encrusted boulders.

4. The absence of a deep-sea fauna from all the even low-level deposits.

5. The absence of any 'zoneing' of the faunas indicative of differences in the depth of the water.

6. The confused intermingling of warm-water and cold-water species.

7. The non-occurrence of true shell beds representing the actual home of the shells.

8. The absence of paired valves of the Lamellibranch mollusca.

9. The fragmentary state of the shells and their (frequently) scratched condition.

10. The absence of any relation between the character of the matrix and the known predilections of the shells for a sea-bottom of a certain character.

11. The fact that no shells or even shell fragments occur within any of the great centres of glaciation, though deposits assumed on other evidence to be marine are observed.

12. The non-occurrence of shells except in association with 'transmarine' boulders.

13 (a corollary to 12). The non-occurrence of shells on the *lee side* of the great centres of glaciation relatively to the Irish Sea glacier.

IX

THE PHYSICAL POSITION OF THE HIGH-LEVEL SHELL BED AT MOEL TRYFAEN

The Moel Tryfaen bed was the first of the high-level drift deposits containing shells which was discovered in Great Britain, and it is recognised on all sides as the *crux* in the great glacial controversy. The champions of the 'Great Submergence' regard Moel Tryfaen as their sure defence, while the advocates of the ice-sheet or great Irish Sea glacier consider that when Moel Tryfaen is disposed of all else is easy.

Previously to a visit to the place anyone would, I think, regard a spur of Snowdon as a highly improbable position to be stormed and scaled by foreign ice.

It would probably be admitted that, with a great head of ice pressing down from the north, even Snowdon itself might be overwhelmed, but there is no need to ask for anything quite so extreme. If the pressure of Snowdonian ice be expressed by the symbol x, then we must suppose an external force of $x + 1$ to overpower it whatever value may be assigned to x.

Paradoxical as it may seem, I think that the general physical character of the Snowdon district is highly favourable to the advance of foreign ice.

Snowdon stands almost on the extreme verge of the Welsh mountains, and by its great height would form a natural barrier against the advance of the inland ice-sheet in its march seaward. We have no grounds for the belief that the native ice could have overtopped Snowdon, so that we have merely to consider the capacity of any snow-fields on the western flanks of Snowdon itself. This must necessarily be very limited, and therefore the work to be done by the foreign ice was confined to thrusting aside a few small local glaciers or dragging them into conformity with the general ice-movement.

There is one feature of the Snowdon district which deserves a few further remarks. The hills fall off with singular rapidity down to the level of Moel Tryfaen, and from that hill the descent is smooth and even until it falls away into the very flat ground which stretches beside the Menai Straits and Carnarvon Bay.

Looking due northward from Moel Tryfaen, and therefore in about the supposed direction of the on-coming foreign ice, there is but one hill, and that of lower elevation and well rounded, intervening between the famous shell bed and the Menai bridge.

There is apparently in the minds of some geologists an idea that it is believed by those who hold with the 'push-up' theory that the *beds* found on Moel Tryfaen have been pushed up out of the bed of the sea. So far as I am acquainted with the literature of the subject there is no foundation for that impression.

What is claimed is, not that the *beds* but that *some of their contents* have been thus uplifted.

X

THE GLACIAL GEOLOGY OF THE ISLE OF MAN

(As has been previously stated, Professor Lewis paid only the one brief visit to the Isle of Man which is described in the Field Notes. Mr. Kendall, however, has studied in detail the glacial phenomena of that island, and regards them as so completely confirming many of the opinions held by Professor Lewis, that I extract from an elaborate manuscript paper he has placed in my hands a summary of what he regards as the chief results of his investigations.)

Summary.—The facts of Manx glacial geology may therefore briefly be summarised thus:—

1. Glacial striæ upon rock surfaces are nearly confined to the limestone region of the south of the island.

2. The direction of these striations varies between W. 27° S. and S. 28° W. (or, as I should prefer to state it, between S. 63° W. and S. 28° W.), a maximum variation of only 35°.

3. The glacial deposits are different in the northern part of the island from those in the southern part; and those of low levels from those of the hill country.

4. The low-level deposits of the north of the island consist of clays with great inter-stratifications of sand and gravel. They contain rock of foreign origin without any admixture of distinctively Manx rock. Shells or shell fragments occur in all members of the series.

5. In the south of the island no clear division of the drift is practicable. The beds contain well-scratched rocks, mainly of local origin, and where clearly identifiable they indicate transport from the east-north-east (Cumming), except in the case of the Foxdale granite, which is found 'in Diluvium' (Cumming), in *very small* quantities, even a few degrees east of south from its natural outcrop.

6. The high-level drift consists of a great mantle of clay containing well-scratched rocks *exclusively local*, which covers even the highest hills.

7. The junction of the high and the low-level drifts in the north is by *interdigitation* and not by *intermingling*.

8. Boulders of the local rocks never occur northward of the parent mass.

9. The Foxdale granite conforms to this rule, and has been carried to west-south-west above its outcrop.

10. The drift hills in the south of the island have their long axes in the direction of the scratches upon the rock surfaces.

11. The foreign rocks include the Galloway granites, a few specimens of such Cumbrian rocks as the Eskdale granite, the Buttermere granophyre ('syenite'), and the micro-granite, with Riebeckite, of Ailsa Craig.

Conclusions

1. These facts prove that the Isle of Man has suffered extreme glaciation by some agent operating in general from the east-north-east, though with minor oscillations to a more northerly direction.

2. That this agent could only have been a continuous sheet of ice moving down from Galloway, with some perturbation by the varying pressure of ice from Cumbria on the one hand and the Firth of Clyde on the other.

3. That there could have been no considerable subsidence of the island in glacial or post-glacial times, otherwise traces would have been left in the shape of well-defined beaches, and of deposits containing shells and foreign stones.

4. That the uplift of the Foxdale granite on to South Barrule furnishes clear proof, taken in conjunction with the absence of similar boulders to the northward, of ice-sheet action, and against any hypothesis in which floating ice could be assigned a part.

APPENDIX B

FIELD NOTES IN SWITZERLAND, ITALY, SOUTH GERMANY, BELGIUM, AND HOLLAND

INTRODUCTORY NOTE

THE subject of this volume being the researches in glacial geology carried on by Professor Lewis in Great Britain and Ireland, his work on the Continent does not come directly within its scope. The following extracts[1] from the Field Notes made in Switzerland and Italy are, however, added, since they both throw light upon some of the controversial questions under discussion, and show how he applied the same methods of study to large continental areas with, as he believed, the same general results.

H. W. C.

SWITZERLAND

[About Basel are terraces and much *stratified* glacial drift, apparently in great part made of jurassic limestone. A good section is seen through the jurassic measures between Basel and Olten. The mountains are made of jurassic limestone.

Signs of glaciation were not noticed on these mountains. No erratics and no drift in the valleys were observed. Fine anticlinal structure and valleys of erosion were also exhibited.

Just south of the long tunnel 'pulpit rocks' of Jura-limestone are well shown.

At Olten we are through the Jura, and now, in the valley of the Aar, stratified drift appears. There is a good cutting in stratified drift close to Zofingen.[1] This cutting is 30 feet deep, showing irregular bedding.

---

[1] Selected by Mrs. Lewis.

We go up the valley of the Wigger, which is marked by flat-topped stratified drift. The valley is bounded by hills.

At last hills of drift, with moraine-like contours,[2] and containing large blocks of limestone, occur. These stretch across the valley like a dam. A village is built on the drift hills. The Alps now come suddenly in view, and I see that there are no mountains between this terminal moraine and the Alps. A small lake also appears, evidently due to the deposition of drift.

Level ground covered by a growth of peat is shortly seen, marking an ancient lake. This point is about one mile and a half before reaching Warewyl. Other lakes and larger ones now appear, enclosed in drift. At Sursee is apparently a dried-up lake.

Pilatus and the snow-covered Alps come into full view.

I am surprised at the limited extent of the glaciated area. I had supposed that the Swiss ice extended beyond Basel. A still larger lake afterward appears, Lake Semp, also enclosed by drift: the lakes get larger and larger as we approach the Alps.

The first one, just behind the moraine, was only 100 feet in diameter, a small pond. The lakes are clearly co-extensive with the glaciated area. This Swiss area is the exact counterpart of the Killarney area, but on a larger scale. At Sempach, and nearer Lucerne, is another and sharper moraine, a second moraine, or moraine of recession. These hills have sharp morainic contours. Or is this rock and not till?

After leaving Lucerne I notice an excellent morainic mass of typical till full of scratched boulders, and well exposed in a fresh cutting one mile before reaching Roth-Kreutz.

About Arth are magnificent exposures of very coarse tertiary conglomerate 'nagelfluh,' being a shore line deposit. More exposures are at Arth-Goldan, where the country is strewed with it. It is an excellent example of conglomerate.[3]

Fine glacial striæ are about Gurtnellen, the granite being smoothed off to 'roches moutonnées,' the smooth sides of which point up the valley. The granite mass shows horizontal cleavage or lamellar parting.

---

[1] Moraine marked in Favre's map. [2] *Ibid.*

[3] Again noticing the 'Nagelfluh' of Arth, I see that it is identical with the miocene of Como. It is a very coarse conglomerate, with layers of sandstone. In both cases it is folded and inclined 45° ±. Here, as in central Italy, mountain-making movements have continued into miocene times. (The making of crystalline schists may also have continued up to this period.)

Quartz porphyry is said to occur here in the granite at Grosser Wind Kellar.

Wonderful railway curves and spiral tunnels here.

The granite is everywhere polished and striated near Goeschenen, the striæ being parallel to the valley, i.e. north and south.

This is one-third of a mile north of Goeschenen.

Lake Maggiore evidently once extended as far north as Bellinzona. The river now meanders through a pile of drift. At Bellinzona the ancient lake forked.

On Lake Maggiore, some miles north of Ganzo-Gera, are excellent glacial striæ on mica schist, which is smoothed off and striated approximately parallel to the lake. Like Lakes Lucerne and Zug, Lake Maggiore is surrounded by mountains and dammed up by glacial till.]

ITALY

[South of Luigi, for several miles along Lago Maggiore, are huge piles of glacial drift. These form hills, which are often precipitous from subsequent erosion. There are many excellent exposures, which show the deposit to be in part stratified sand and gravel, in part stratified clay, in part unstratified boulder clay. It appears to be a portion of a great moraine which, perhaps, dammed up the lake.

At Laveno-Manbello is unstratified till. It is clear that the Italian lakes also are due to the choking up of pre-glacial river channels by drift.

Lake Lugano, according to Harada's map,[1] is also dammed up by drift. While the pre-glacial river channels may have been due to faults or cracks in the rock, the lakes are more modern and of glacial age.

A mass of morainic drift with many large boulders occurs north of Sesto Calende, which latter place is at the end of the lake. About two miles beyond Sesto Calende is the great terminal moraine of the Swiss ice-sheet, several hundred feet deep.

It contains huge boulders 6 feet across. The railway makes two tunnels through this moraine. The moraine here increases, it is miles in width. Much of it is horizontally stratified, and the river has cut a fine gorge through it.

---

[1] N. J. Beil, Bd., 1882.

The moraine is now tunnelled by the railway, which then skirts it for some miles. The front part is made of clay (?). (For extent of this moraine see geological map of Italy.) It is the largest moraine I have ever seen. Why do all the chief glacial centres shed the greater part of the ice southward?

To-day I have seen the terminal moraine to the north and to the south of the Swiss centre of glaciation.

There is a fine *glacial moraine* at Carrara. The moraine is now a hard conglomerate cemented by lime. Large blocks and pebbles of marble and of schist lie imbedded irregularly in a calcareous mass, and form large hills.

It is well seen in the valley behind Carrara. The railway makes a tunnel through the morainic débris at one point. Striæ occur higher up on the mountain.

Another glacier occurs at Masso. In all there are seven glaciers in the Apulian Alps, three on the sea-side, and four on the east side, the latter being the largest. (See papers by Corci and Dr. Stoppani.)

At Verona is a great level-topped plain of stratified drift, the pebbles coarse, and terraces occurring where rivers have cut through the drift.

It is an extensive plain and is identical with that about Münich.

This plain continues up to Sommacampagna, where, at the railway station, a fine terminal moraine rises abruptly out of the plain in the form of a ridge heaped up in characteristic morainic contours.

This ridge is filled with boulders,

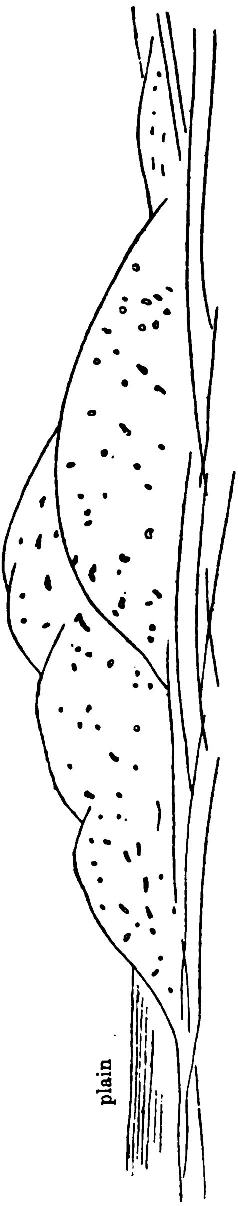


FIG. 58.—Moraine at Somma Campagna.

often large, is partly stratified and partly unstratified, and contains clay, gravel, &c. The ridge rises abruptly out of the plain, but behind it the land is undulating and deeply covered by drift.

About half a mile back of this outer ridge is another smaller one, apparently somewhat parallel to it.

Still larger masses of drift occur farther beyond.

Then comes a plain in which lies the beautiful lake 'Lago di Garda.'

The Tyrolese Alps rise on the north side of the lake, while on the south it is dammed up by drift. The lake appears to have been larger than it is now.

Moraine hills are seen south of the railway. There is a beautiful view from Desenzano—village, lake, and mountains to the north, and to the south a high moraine.

The moraine is cut by the railway half a mile west of the station.

It is unstratified, is full of large boulders, and is a genuine till.

Sonato is built upon it, and here, immediately below the old walls of the town, is a cliff exposing a good section of it. The moraine is thus several miles broad.

At Sonato we leave the moraine and enter upon another plain of stratified drift. From this plain, west of Sonato, is a fine view of the terminal moraine, which is like a great dam abutting against the mountain.

No signs of glaciation are here, or at Brescia.

Another plain of stratified drift occurs west of here, and a distinct terminal moraine is seen north of Rovato.

North of the moraine is Lago di Iseo. The moraine stretches across the valley like a dam.

Each of these moraines clearly bounded separate ice-tongues, unlike the moraine of the North American ice-sheet.

In topography and appearance these moraines are identical with that in Pennsylvania, except that in Italy they are more distinct and often larger. The smaller the glacier the larger is the moraine in proportion.]

MILAN TO BELLINZONA

[A great plain extends from Milan northward to a large terrace formed of pebbles cemented by lime into a rock-like mass. This terrace is 75 feet high, making an elevated plain much like that at Berwick, Pennsylvania. The terrace becomes higher as we go northward. Good exposures are on the railway. It is a compact, hard mass of stratified gravel, with clayey till below, and also clayey parts above.[1]

Farther north the drift is yet more massive, the hills rise to the height of several hundred feet, and we pass into the moraine itself. The moraine proper is made of rounded knob-like hills, sprinkled with large boulders, and the country becomes uneven.

Albate lies in this region. South of here tunnels are cut through the drift, and to the north is Como, the lake and the beginning of the mountains.

At Como is a great mass of coarse conglomerate rock resembling moraine material, except in being well rounded. It is of miocene age. This miocene shore rock resembles the 'Nagelfluh' of Arth, and has supplied much material for the drift.

Lago Maggiore is clearly diminishing in area, as the moraine dam is being gradually cut through by the Ticino. As is shown by the plain of drift, the lake clearly once extended up to Bellinzona, where it forked (vide Geol. Map of Italy).

There are no dams of drift above the lake, but a level plain which runs in under the lake. The dam was once higher and the water was backed farther up into the pre-glacial valley. No scooping action of the glacier has been observed about any of these lake basins, and they are all due to drift dams.

(This being the case, the 'loess' of the Rhine is perhaps also due to a dam. Was the dam at the southern end, and was the drainage reversed ?)

Excellent glacial striæ and polishing occur at Osogna on hard granitic gneiss. Here also are quarries of the rock.]

SWITZERLAND

In Baden, south of Mülhausen, the Rhine Valley is filled with gravel, which shows cross-stratification and a flow and plunge structure. The dip of the gravel layers is toward the north, i.e. in the direction of flow of the gravel-laden flood.

J. DELBOS and J. KOECHLIN, On the Drift of Southern Elsass about Mülhausen, &c. See *Description Géologique et Minéralogique du Département du Haut-Rhin*, Schlumberger, Mülhausen, 1866; vol. ii. p. 86 *et seq.*

The 'gravier, ou diluvium rhénan ou alpin,' is made of rocks of the Alps south of Lake Constance, mainly protogene, black limestone, &c., with which are mixed some rocks from the Black Forest and Jura (light limestone).

---

[1] See Godwin Austen, *Q. J. E. S.*, 1884, p. 855.

The pebbles are well rounded, and diminish in size as one goes northward from Basel.

The pebbles from the Vorder-Rhein are much more rounded than those from the Jura.

At St. Ludwig are extensive terraces of drift. At least two terraces occur here, being made of coarse gravel. This continues to Basel, where are also extensive drift terraces, rising still higher.

In Switzerland, south of Basel, at Niederschönthal, are moraine-like ridges, made apparently of till. These are well shown about Liesthal, where the railway at the station cuts through drift. The river appears to have cut its channel through these moraines, which, perhaps, form dams across the valley. Just south of this is much stratified drift.

South of the Jura at Roggwyl are high terraces of stratified drift.

About Münsingen, between Berne and Thun, is a *moraine*.

At Berne, in the museum, are glaciated boulders (all showing southward transport) of

Gabbro	found at	Bieler See.	Glacier	carried	from Saasthal
Serpentine	„	Muleberg	„	„	„
„	„	Ferenbahn	„	„	Zermatt
„	„	Bumplatz	„	„	„

For glaciation see:—

Favre, *Carte d'Anciens Glaciers de Suisse*, 20 pp., Berne, 1884.

Jahrb. Schweitz. Alpenclub, &c.

Also Forel, *Les Variations Périodiques des Glaciers des Alpes. Echo d'Alpes*, XVII., for 1880; XVIII., for 1881: *Jahrb. A.C.* for 1882, 1883, 1884.

Richter, *Der Rückgang der Alpengletscher*, Ausland, lvi. 74, 1883.

Frey, *Gletscher-Schwankungen, Zeits. deutsch. u. öster. Alpenvereins*, 1883.

GRINDELWALD

[I studied the Upper Grindelwald glacier. A large moraine (?) lay outside of the ice. Striæ *on the large boulders* which lay in part of the ice, as well as on the rock floor in front of it, were all parallel to the modern glacier.

The boulders evidently were striated by having sand pushed over them by the ice. They were not striated by being themselves pushed along while frozen in the ice. They all lay with the striæ running over them on top just as if they had been solid rock. They made a 'glacial pavement.' The striæ were all parallel, and both on the boulders and on the solid rock in front of the glacier the individual striæ were observed to be thickest,

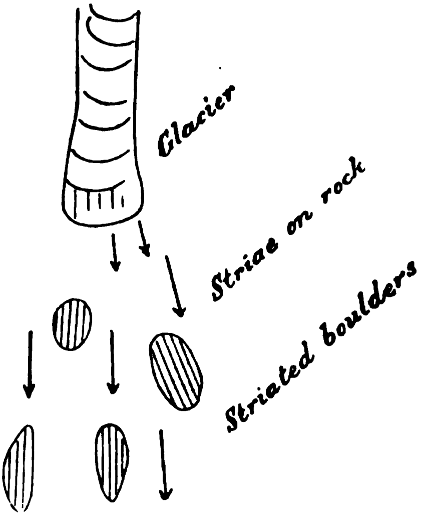


FIG. 59.—Sketch of Striæ on Rock and Boulders, Grindelwald Glacier.

FIG. 60.—Striæ at Grindelwald.

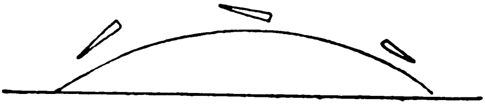


FIG. 61.—Striæ on up surfaces.

and bluntest at the end *towards* which the glacier was moving. This is particularly the case on *up* surfaces, *not* on down ones. I also observed it on level surfaces and on side surfaces. Boulders often when large showed lee and stress sides. In the cave cut in the glacier I saw a beautiful furrow in the ice made by its advance. This showed the motion to be much faster above than below.

The curves were precisely like those in a viscous mass of tar. Beautiful. Ice-blue.

Layers of *sharp sand* occurred here and there in the glacier.

This is the grinding and cutting tool, not large stones.

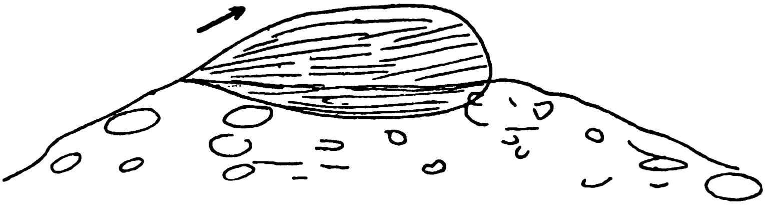


FIG. 62.—Boulder showing Lee and Stress Sides.

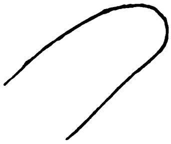


FIG. 63.—Furrow in Ice-cave in Grindelwald Glacier.

Sharp sand does cut and striate clearly. The layers of sand with small stones in them rise as the glacier descends.

This *rising* of the layers of sand was finely shown in the artificial tunnel. The strata of sand were straight.

The bubbles and impurities in the ice rose likewise, being parallel to the sand layers, but by no means parallel to the floor of the glacier.

(Seen also in the Lower Grindelwald glacier.)

This fact is very important as explaining the rise of boulders to points higher than their source in ancient glaciers. The fact also that the terminal moraine was not so high as the ice-wall is important as explaining how far-carried boulders often occur beyond, or higher up, than the main moraine, as in the fringe.

The moraine is *pushed* along and also has boulders *dropped* upon it from above; hence the mixture of materials, while the fringe[1] is only the *dropped* material.

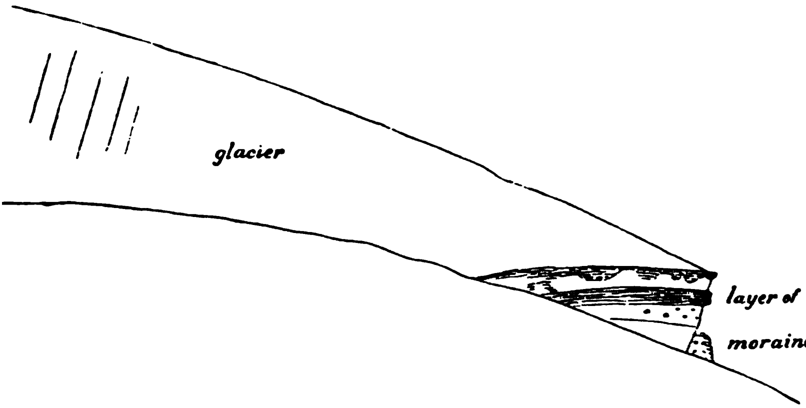


FIG. 64.—Upward Motion of Layers of Sand in Grindelwald Glacier.

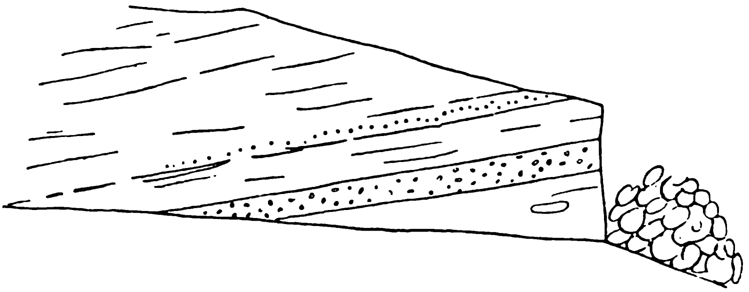


FIG. 65.—Diagram showing Lines of Sand in the Glacier abutting against the Moraine.

A small moraine or mound of stones had been pushed forward by the Grindelwald glacier, which advanced over 20 feet during the last winter—according to my guide. He said that stones were continually falling from the front top of the ice.

---

[1] That is to say, fringe of one kind: the fringe formed in extra-morainic lakes by boulders dropped from floating cakes and rafts of ice has already been described.—J. F. L.

I collected glaciated pebbles of limestone from the moraine hills in front of the glacier.

Tracings were made on large boulders which were striated by being overridden.

I find that the blunt end of striæ is frequently due to a crack or imperfection in the rock which is being polished.

Lines often stop at a crack or cleavage line.]

New markings on glacial boulders

When in Berne, Professor Baltzer showed me boulders of quartz covered with perlitic concentric circles, which were scaly depressions of spherical or conical form, like onion skins. They appeared to be *cones*, with the apex outwards, being percussion bulbs, *compression cones*, or whatever we may choose to call them, due to the rolling and pounding of the boulders beneath the ice.

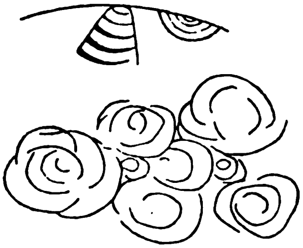


FIG. 66.—Percussion Cones on Glacial Boulder.

The boulders were *tools* heavily crushed under the ice, and these interesting structures are due to pressure at successive points as the boulders were rolled along.

A section of a boulder shows that these markings are concentric percussion cones with the apex outwards.

Mühlberg called Professor Baltzer's attention to these. The surface of the boulder is covered with irregular rings, resembling perlite.

I shall probably find these elsewhere.

[I climb up to Baregg, and then cross the Lower Grindelwald glacier to Zäsenberg.

Many streams are on the surface of the ice and at the side of it, and, on the sides of the moraines, and pouring into crevasses. The ice is much higher in the middle than at the sides. The

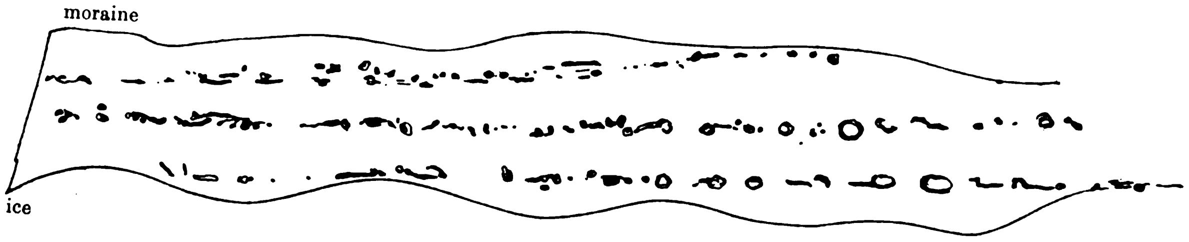


Fig. 67.—Lines of Stratification in Lateral Moraine. Grindelwald Glacier.

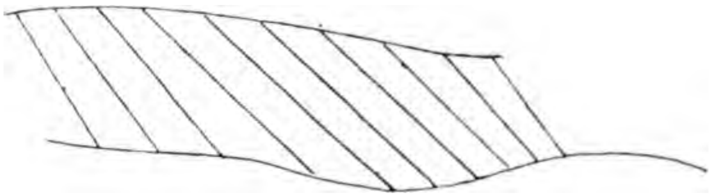


Fig. 68.—Sketch showing Dip of Blue Bands in the Ice.

lower part of the glacier is covered by débris, all of it being angular and non-glaciated.

The lateral moraine opposite Zäsenberg shows lines of stratification, and the larger stones are all in rows or lines, and flat lying, being identical with the moraine opposite Thun at Thungschneit. Blue bands in the ice dip sharply up hill. .

The glacier is very steep at its border, and water runs down from the surface of the glacier to its edge.

At Zäsenberg, which is an island in the glacier, is a grand moraine.

The sharp ridges on each side of the glacier are lateral moraines, and a stream runs between these lateral moraines and the rock, making much sand.

Angular sand is 3 to 4 feet deep in places at the foot of Zäsenberg in the moraine.

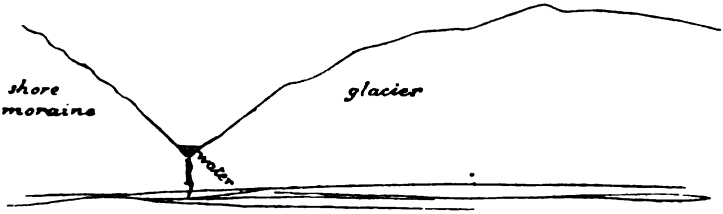


FIG. 69.—Diagram showing Water between a Glacier and the Shore Moraine.

Streams also often occur just inside of a lateral moraine. We may thus get a moraine unstratified, and angular in the centre, and sandy on each side (fig. 69).

Four streams may occur, one on each side of each moraine (fig. 70).

There is a fine sharp medial moraine below Zäsenberg. The lateral moraines are ridges, even on top, but the medial moraine is hummocky.

The hummocks are made mainly of angular sand overlying hummocks of ice (fig. 71).

Remarkable conical hills of ice often occur on the glacier, and are covered with sand and boulders. The ice in these hummocks is pure and compact, and used for export, while the ordinary glacier ice is soft and snowy.

The medial moraine is sometimes 50 feet high or more, in sharp hummocks, and is made of ice, covered by drift. The

hummocky form is a chop-sea of ice, which at the meeting of two glaciers rises in great ice-waves, being pushed up by the pressure of the ice. Thus the present form of the medial moraine as a ridge is due to the form of the ice, this form after the melting of the glacier being, of course, modified. Kettle-holes result from the melting of ice-cones, covered and preserved by drift.

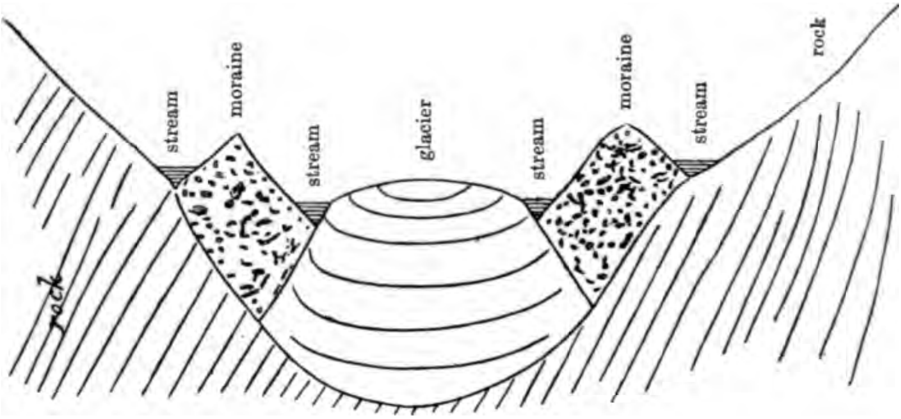


FIG. 70.—Section of a Glacier, with Lateral Streams.

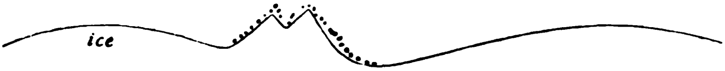


FIG. 71.—Sketch showing the Formation of a Medial Moraine.

It is an important fact that the drift is not pushed up into a ridge, but the ice itself.

In portions of the glacier covered by sand and drift the ice remains in remarkable hummocks, which unless so covered would have been melted by the sun and levelled down.

I examine the end of the glacier.

The ice is here so covered by débris that it is difficult to decide whether I am on the glacier or not.

Masses of ice, detached from the glacier, lie covered by drift and protected from melting. Where it melts kettle-holes naturally result. The *origin of kettle-holes* in moraines and kames is thus clearly shown.

Whittlesley's idea is confirmed.

A good section of the glacier at the end shows it to be made of a series of concentric curved bands, *concave.* These bands are very regular, and may be seen in photographs.

They are, perhaps, connected with the sharper dipping blue bands which are seen in longitudinal clefts. We would thus have as (1) *cross section*; (2) *longitudinal section*; thus making a series of *sections of a cylinder* to compose the glacier (fig. 73).

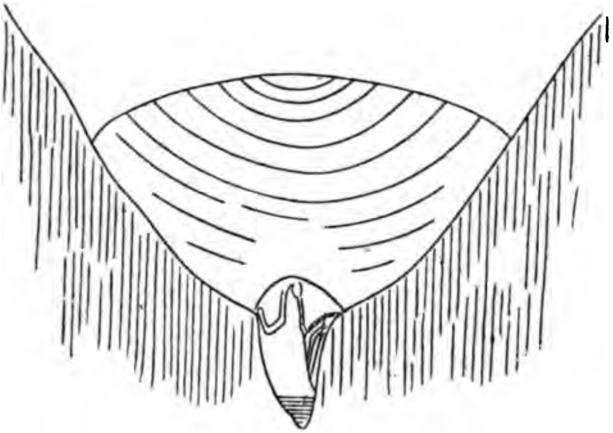


FIG. 72.—Section of a Glacier showing the Concentric Layers of Ice.

These cylindrical or conical sections slide over one another. In the glacial grotto cut artificially in the end of the ice I see lines of bubbles and of sand, not horizontal, but dipping up stream at a much gentler angle than the blue bands I had seen farther up in the 'eis-meer.' They are clearly the same as the blue bands; the stripes getting more and more horizontal from the 'eis-meer' to the end of the glacier (see fig. 74).

Above and outside of the glacier, near its lower end, are magnificent rock-groovings and scorings, the finest that I have seen anywhere. They are on limestone.

The finer striæ, both on vertical and on horizontal faces, are generally deepest at the farther, or *down,* end. The large

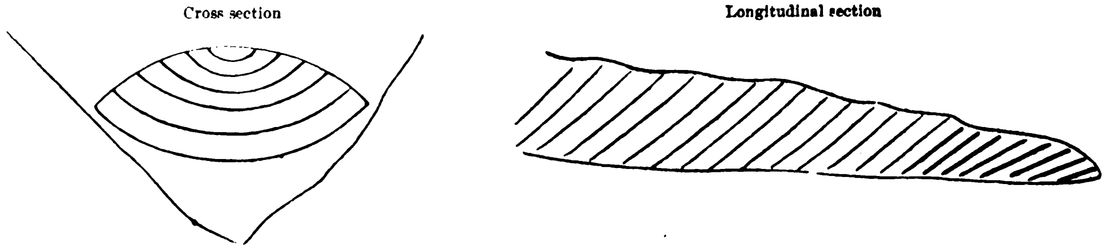


FIG. 73.—Cross and Longitudinal Sections of a Glacier, showing Concentric Bands.

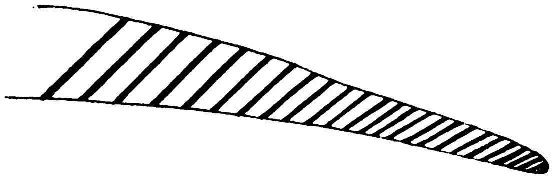


FIG. 74.—Section showing the Dipping of the Blue Bands.

FIG. 75.—Stone on a Pedestal of Ice.

grooves are many feet in diameter. According to my guide, Christian Almer, the glacier reached up to these grooves and stretched far down into the plain, perhaps 1,000 feet. It has retreated greatly, but last year advanced somewhat.

The Upper Grindelwald glacier has advanced some 20 feet during the past year (1885), and also 20 feet the year before. The glacier in melting makes a small *pond* between the ice and the terminal moraine. This is like the Marjelen See and other lakes. (CHARPENTIER, *Essai sur les Glaciers*, p. 66.)

On the glacier I saw stones perched upon pedestals of ice, the stones dipping *up* stream. These stones often slip off.

I also saw stones occasionally falling into crevasses in the middle of the glacier.

But nearer the end of the glacier all the stones were on top, and the ice at the end was pure and free from all but fine sand. The stones were therefore shed to the top of the ice, from which they were constantly falling. (CHARPENTIER, *Essai sur les Glaciers*, p. 68.) Venetz was the first to explain how stones were brought to the surface of glaciers. (*Sur les Glaciers*, 1816.)

An open crack sometimes intervenes between the glacier and its enclosing wall of rock. Into this crack stones fall and are pushed along slowly, making striæ.

In some places the glacier rises at least 150 feet in the middle above its sides.

Most of the crevasses are transverse, but longitudinal and others occur, and when the glacier curves they are radial from the concave to the convex side, &c.: many of the crevasses are curved slightly, others crossing, &c.

The open crack at each side of the glacier is due in part to the heat of the adjoining rock warmed by the sun. (CHARPENTIER, *Essai sur les Glaciers*, p. 80.)

On vertical cliffs at the lower part of the glacier the striæ *descend*, but those on vertical cliffs farther up and higher, made when the glacier was very much larger than now, ascend, as I noticed at the Delaware Water Gap, in Pennsylvania, and at other places in the same State, and also in Ireland. (Report Z, pp. 107 and 275.)

I saw on a flat rock in front of the glacier cross-striæ made apparently by a single stone which turned over, as seen in Monroe, county Pennsylvania. (Report Z, p. 85.)

The *ascending striæ* on a vertical face of rock, seen where the glacier was thick, are interesting as proving the actual upward motion of sand, &c., in the glacier, as indicated by the blue bands and the lines of bubbles. In Report Z, p. 275, they are observed as concave on the upper side, and dipping 20° up stream.

Beneath the glacier, as exposed by its recession, is an interesting gorge of a subglacial stream.

The gorge of Lütschine must have been made by water beneath the glacier, and when discussing supposed post-glacial gorges, cases of this kind must be taken into account.]

Note.—On the rising of gravel and boulders from the bottom to the top of the ice, see HUGI, AGASSIZ, FORBES, MARTINS, &c.

HUGI (*Ueber das Wesen d. Gletscher*, pp. 100–104) says that the shedding out or raising to the surface of foreign bodies is one of the most certain facts known. In Swiss glaciers stones have been known to rise 20 feet and more in a single year.

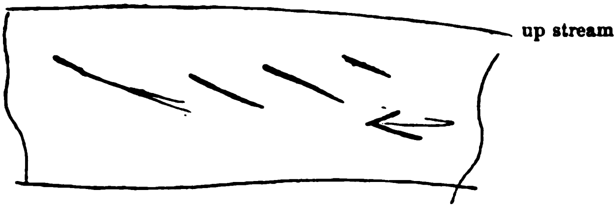


FIG. 76.—Sketch of ascending Striæ.

Not only sand particles but granite blocks of 20,000 cubic feet are thus drawn upward to the surface. Rocks which have fallen into crevices in the autumn are next spring found on the surface, the glacier continuing of equal size and moving on.

He rightly combats Agassiz's idea that they were shoved up by the freezing of water in the cracks below them.

AGASSIZ (*Untersuchungen über die Gletscher*, p. 97) speaks of the same phenomenon and ascribes it to the pushing upward of freezing water in cracks. [Mistake—see Hugi.]

CHARPENTIER (*Essai sur les Glaciers*, p. 68) explains the fact of the raising of stones to the expansion of the glacier combined with superficial melting. [Mistake—melting need not take place.] In fact the melting is more under than on top of the ice. (Hugi, 118).

VENETZ (*Soc. Helv. des Sciences Naturelles*, 1816) was the first to offer an explanation for the phenomenon.

HEIM (*Gletscherkunde*, p. 359) treats of the same thing, and refers to Seve's conclusion that medial moraines may have been raised up.

INTERLAKEN

[The two lakes of Thun and Brienz, once connected, lie in an old pre-glacial valley whose outlet has been filled by drift. Many boulders of granitic gneiss, gneissic granite, &c., lie about Interlaken, being derived from the inner part of the Bernese Oberland.

On the road to *St. Beatenberg*, on the north side of Lake Thun, I observed a fine morainic mass of till heaped up on the side of the mountain.

This till is full of boulders, many of them striated and often of large size. The mass of till is very deep (over 100 feet), and is well exposed in several ravines at a height of 3,800 feet, being over 1,900 feet above Interlaken.

It contains large boulders of syenite, granite, &c., brought from the Jungfrau region, which are scattered among the more numerous boulders of local origin—all embedded in glacial clay and often scratched. It appears to be a fine terminal moraine heaped up on the southern slope of the mountain by the glacier which filled the valley. In a ravine at the bend of the road is a fine exposure of till, full of boulders, often striated, in which, however, I could find no granite or gneiss, although somewhat lower down both are said to be abundant. I found boulders of protogene gneiss, abundant above Stechelberg, at the head of the Lauterbrunnen Valley; near Mürren jurassic limestone and cretaceous shale outcrop.]

LUCERNE

[The Lion of Lucerne is cut in soft sandstone (molasse), in which is a narrow band of nummulitic rock which appears at the 'Glacier Garden.'

Magnificent pot-holes occur here, also erratics, and striated rock surfaces. Here also, as a rule, the broader ends of scratches are toward the direction of motion : i.e. to the *north*.

The Rigi is made of a great thickness of miocene conglomerate ('Nagelfluh polygentian'). The pebbles are of limestone, red granite, sandstone, &c.

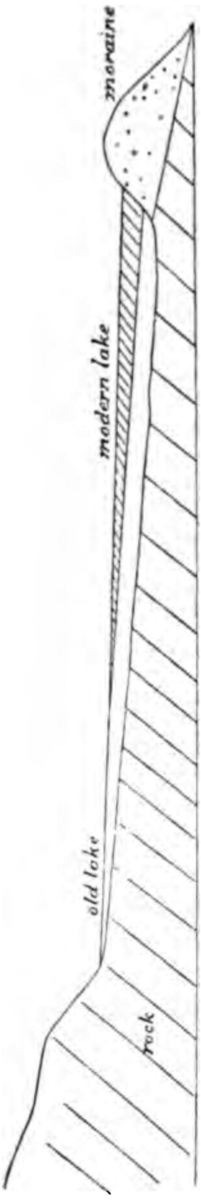


Fig. 77.—Section showing the Formation of a Moraine Lake.

Granite pebbles are abundant at the Rigi Kulm Hotel.

Slickensides often occur in this conglomerate, and the pebbles themselves frequently show slickensides.

The sliding pressure which has thus striated the pebbles (so that some of them resemble glaciated stones) has also gouged pieces out of the individual pebbles, and has produced curious finger-like depressions on them, especially on those made of limestone.]

(See Rothplatz, *Ueber Gerolle mit Eindrucken. Z. D. G. G.*, 1880, 189.

O. Heer, *Biographie, A. Eschers v. d. Linth,* where the latter observed this in 1883.

Von Dechen, *Sitz. Nied. Ges. f. Natur- u. Heilkunde*, 1849.

Gumbrl, *Geogn. Bisch. Fichtelphyr*, 1879, p. 479.

Daubrée, *Etudes Synthétiques de Géol. Expérimental*, 1. 1879, 382, and Rothplatz, *Ueber mechanische Gesteinsmisshandlungen. Z. D. G. G.*, 1879, 355, and Naumann, *Geognosie*, 1. p. 413, where many examples and references to literature are given.)

[Every lake that I have seen in Switzerland is due to the damming up of old valleys by moraine drift. The drift dam of the Interlaken lakes occurs to the west of them; that of Sargen Lake is north of Sargen; that of the Lake of Lucerne is north of Lucerne; that of Lake Zürich is in the town of Zürich. I have seen no evidence of glacier excavation.

All these lakes also are diminishing in volume, as is seen at their upper ends.]

SCHAFFHAUSEN AND SINGEN

[South of Schaffhausen are hills of till. Between Schaffhausen and Singen are hills of stratified drift and till.

About Herblingen, for example (east of Schaffhausen), are large drift hills, and the region is deeply covered by drift, some of it unstratified, as is seen in the railway cutting just east of the station. Moraine? One mile east of the station rock occurs, and continues to outcrop for some distance (jurassic limestone), and we thus sharply pass into the non-glaciated region.

Again, however, we enter the glaciated region and the moraine between Thayingen and Gottmadingen.

It consists of low rounded hills of drift, and the railway runs along the outer edge of the moraine apparently. Gottmadingen is on the extreme edge of the drift, and characteristically shaped moraine hills occur along the railway between here and Singen.

About Singen, and north of it, is a plain of stratified drift. Hohentwiel rises above the drift.]

SWITZERLAND

[There is a good exposure of till back of the Titi-See Station, Schwarzwald, which is now being dug. It is a dirty clay full of coarse sand, grit, angular fragments, and boulders. Some of these are clearly striated, and two large ones have been placed on the platform of the station.

The exposure is exactly like that which I photographed at Bangor, Pennsylvania.

The Titi-See is dammed up by moraines.

Near the lake the drift is stratified.

It is an angular, coarsely stratified, half-washed gravel, identical with that on top of Three Rock Mountain, Dublin. That is no more a sea-shore deposit than this is. They are absolutely identical. A coarsely stratified angular gravel contains lines of sand. This is close to the Schwarzwald Hotel.

West of Ober Holsteig a moraine forms a great dam across the valley, and makes a watershed.

The numerous fresh cuttings along the newly opened railway give an excellent opportunity for comparing the true moraine drift with the talus and avalanche débris which cover the sides of the mountain, and often make large heaps in the valley. The latter is made entirely of *angular fragments*.

The fragment may be rubbed on one or more sides or angles, but no round boulders, no gravel, and no stratified sand appear. The rounding of the surface boulders due to weathering can be distinguished from glacial rounding.

In the moraine the boulders are almost all more or less rounded, and sometimes traces of striæ on them can be seen. The rounding is not like that on cobble-stones, since the ends of many boulders remain rough.

The natural character of the moraine is well shown near Ober Holsteig, where it is covered by forest, and some trees have lately been cut. It is thickly strewn with large boulders, so that one could step or jump from one to the other. It is identical with the Pennsylvania moraine.

In company with Professor Dr. A. Baltzer, of Berne, I made some glacial studies in the neighbourhood of that town. We saw a good medial moraine joining an end-moraine, thus:—

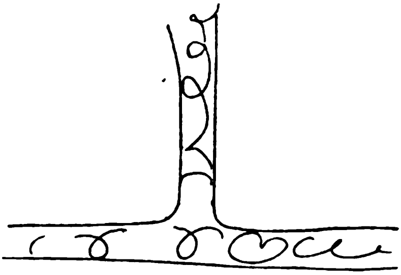


FIG. 78.—Sketch of Medial Moraine joining End Moraine.

The ground moraine was sandy, very few boulders scratched—and partly stratified. It looked like Three Rock Mountain stuff.

At Himli Wald is an excellent terminal moraine with typical structure, dirty, clayey, rough, full of large blocks and unstratified. Like the Pennsylvania moraine, it is rougher and less stratified than a 'ground-moraine,' and contains more scratched boulders.

The moraine at Gümlingen Station is a large lateral moraine, full of erratics and striated pebbles, containing occasional layers of stratified tough clay and sand, as shown in a fine exposure: being a typical moraine structure. Near here the glacier certainly went *up hill*, going from Gümlingen towards Boltigen. In one place the push of the glacier is well shown; the south side of the stratified moraine being contorted and shoved back by the push. (See Baltzer, *Geol. Mitth.*, *Mitth. Naturf. Ges. in Berne*, 1886.) We see also that the stratified moraine was made before the second advance of the glacier. I see no typical kames, these being stratified longitudinal moraines.

Sand is often seen under the moraine material.

Near Stellen is the *great terminal moraine*. It extends to Boltingen. It is typical, stratified at the back, and hard to distinguish from a kame. Kames are made at the back of a moraine. Like the marginal kames in Pennsylvania, which are clearly part of the moraine. Not distinguishable here from the moraine. The moraine makes high hills; typical. It is interesting to find so many of the moraines about Berne stratified.

It seems that the inner side or back of the moraine is generally stratified, and thus we get passages into kames. I cannot draw any sharp line between the stratified and unstratified moraine material.

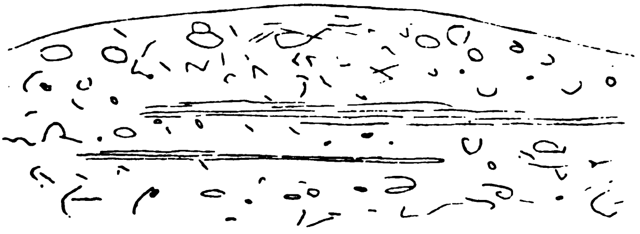


FIG. 79.—Section of Moraine, near Gümlingen Station.

The ground moraine here is all stratified.

The stratification was done during the retreat of the ice. At the foot of the ice, just outside of it, water seems to have bordered the glaciers during their retreat.

The greater part of the moraines here were formed after the ice had divided into small tongues at its last stage.

But moraines of the ice-tongue at the time of maximum glaciation also occur, as on top of the Belpberg, and at Bollikofen.

A large and typical moraine finely heaped up, and enclosing moraine lakes, occurs on top of the Belpberg. This is a fine lateral moraine; elevation 895 metres.

The high-level moraines here are almost unstratified, but those at lower levels are stratified.

The ground moraine has been stratified by waters issuing from the foot of the glacier, 'Gletscherboden.'

Often, also, water lies *between a glacier and its moraine*, making stratified deposits.

Nowhere do I know of a better exhibit of moraines of recession, or of evidence of the halting retreat of a glacier. (See Favre's map.[1])

The moraine near Steinhof is massive and broad, but not high, this being a characteristic feature of the moraines of ice-sheets ('inland eis'), as distinguished from the narrow, sharp, high moraines of tongue glaciers.]

The following is an extract from *Die erhaltenen Findlinge im Kanton Bern*, J. BACHMANN, Berne, 1870 (an admirable work), p. 7:—'On the *right side of the great Aar glacier* erratics from the Grimsel and the Gadmen predominate, while on the left are erratics from the Lauterbrunnen and Kander regions.'

[Important distinction from a river. Less intermingling than in a river.]

BERNE TO THUN

[At Ostermundingen is a good moraine. It crosses the valley and rises to the hills on either side as a series of knobs and ridges.

I see many longitudinal kames, or moraine ridges, which are usually stratified, yet are regarded as moraines.

Bachmann ('*Der Kander*') suggests that in wide ice-sheets, or where the glacier opens out from a valley into an open plain, longitudinal cracks occur, into which detritus, borne on or in the ice, falls, or is carried by streams. I suspect that we here can understand the passage from kames into medial moraines. When the material is *dropped in* we get a 'längs' moraine; when it is *washed in*, a kame. The latter would naturally be made during a period of melting, or a moraine might at the same time be transformed into a kame. In Maine (U.S.) moraines pass into kames (Stone), and in Pennsylvania kames occur at the back of moraines, 'marginal kames.']

---

[1] A succession of parallel terraces one above the other are seen on the sides of the Belpberg, being particularly distinct at its southern end. The summit of the ridge is crowned by a long moraine of typical hummocky contours, with erratics, lakes, &c. The terraces lower down are also of glacial origin, being probably lateral moraines made during the different phases of the melting and retreat of the glacier.

The whole hill shows evidence of moulding by ice; there being a gradual ascent at the southern end and an abrupt one at the north, as though it were a huge 'roche moutonnée.'

The hill is made of miocene molasse (and *Nagelfluh*), crowned by the glacial moraine.

These terraces may be compared with those of the Yorkshire glacier.

THUN

[I walked across the old lake plain to the fine moraine at Amsoldingen. It consists of a series of parallel ridges running parallel to the flow of the ice, being longitudinal moraines. Very large villages are built upon it; typical.

Two exposures show it to consist of unstratified moraine till, and a photograph taken here would be identical with that taken

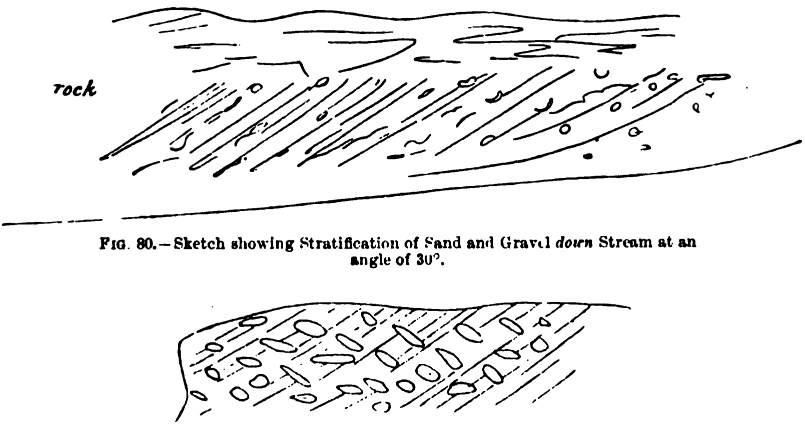


FIG. 80.—Sketch showing Stratification of Sand and Gravel *down* Stream at an angle of 30°.

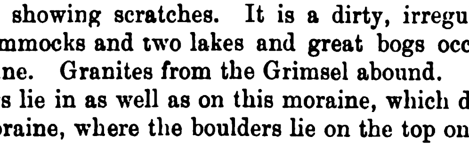


FIG. 81.—Sketch showing individual Pebbles inclining *up* Stream.

at Bangor, Pennsylvania. Scratched pebbles abound in it, nearly every stone showing scratches. It is a dirty, irregular, dump-mass. Hummocks and two lakes and great bogs occur in this large moraine. Granites from the Grimsel abound.

Boulders lie in as well as on this moraine, which differs from a sandy moraine, where the boulders lie on the top only.

This fine and large moraine, made of several ridges, extends for many miles along the valley.

I climb over a ridge of avicular limestone, finding many erratics, and then another smaller moraine behind it. At the village of Moos, close to the mountain, is a hummock of stratified moraine. Here the pebbles are half worn, being moraine matter altered by water; it resembles the moraine on Three Rock Mountain, near Dublin.

Near Wimmis the Kander cuts through a massive terrace deposit, consisting of very coarse gravel and sand, well rounded and coarsely stratified. It is very interesting to know that this great terrace is modern, made since 1714, when the Kander was led through the damming moraine. *The lowering of the outlet of the river* made the terraces. Important explanation of many terraces (see BACHMANN'S *Kander*, p. 16).

Originally it had very low banks, wandering in a broad plain northwards to Uttigen.

The pebbles are unusually large, sometimes 18 inches long, and the stratification is highly inclined *down stream*, often at an angle of 30° (fig. 80).

The individual pebbles, on the other hand, incline *up stream*, as they do near Cork, in Ireland (fig. 81). It is a good example of strong river-action.]

UTTIGEN

Bachmann says ('*Der Kander*,' p. 88) that in the tough clay underlying the '*Nagelfluh*' he has found striated erratics of Grimsel granite, &c., as if borne by icebergs in a lake from the foot of the glacier.

This would indicate that the whole deposit was made before the glacier had advanced here, but when a glacier filled the Haslithal, &c., having a greater extension than now. I am coming to think that there was a first glacial epoch which was *much less extended* than the second one, but which furnished large rivers.

The glacier in this epoch probably did not extend as far out of the mountains as Thun.

Evidence of this first glacial epoch is also given by Penck, from Innspruck, which was, perhaps, the limit of the first glaciers. There was a period of flooded rivers between this epoch and the second. The *löcherige Nagelfluh* there was made in the early part of the glacial period.

Bachmann classes this deposit among those made during the advance ('Vorrücken') of the glacier. So are drumlins made at this time. It is very questionable whether we should not regard this as the early part of one glacial epoch.

Two ice periods

[I can find no evidence of two distinct ice periods. But see Heer. It is probable that the first ice period was marked by less extension of ice than the second. There seems to have been an advance, then a retreat, then the great advance at the period of maximum glaciation, then a retreat by steps and halts and oscillations.

The supposed evidence of two periods are very local facies of the drift.]

Kinkelin (*Ueber die Eiszeit*, Lindau, 1876, p. 50) shows that the supposed evidences at Durnten, &c. (lignite) are only local, and Professor Baltzer told me that he was unable to find the two tills at this place.

Favre well remarks that the Chamounix glacier, which in 1808 retreated 2,000 feet, and which, if it again advanced, would cover over stratified gravels and perhaps trees, equally gives evidence of two glacial periods.

The terminal moraines are often spoken of as the moraines of the second glacial period (MÜHLBERG, *Ueber die erratische Bildungen im Aargau*, p. 158, &c.).

FRAAS, *Begleitworte zur Geog. Sp.-Karte und Württ. Bl. Leutkirch und Jsay*, p. 14 ; but this is a mistake.

The 'ground moraine' of the first period in Hohenzollern is the *löcherige Nagelfluh.*[1]

Temperature of glacial period

According to Heer, in Switzerland it was less than 10° F. colder, but was damper than now.

According to Sandberger, Würzburg then had the temperature of St. Petersburg now.

BERNE TO ZUG

[In the valley between Gümlingen and Rubigen is a medial (or *längs*) moraine, moulded into the form of a drumlin, the flat end pointing south, from whence the ice came (fig. 82).

By a medial moraine I do not mean one made by the joining of two glaciers, but simply an internal *longitudinal moraine.*

I shall use the latter name as near the term 'längs-moraine, which includes medial, lateral, and longitudinal moraines.

In the large lateral moraine at Gümlingen Station I collect

---

[1] Heer and Desor hold with me that the *second ice period was that of its greatest extension.* (See *Penck*, chapters xx., xxi.)

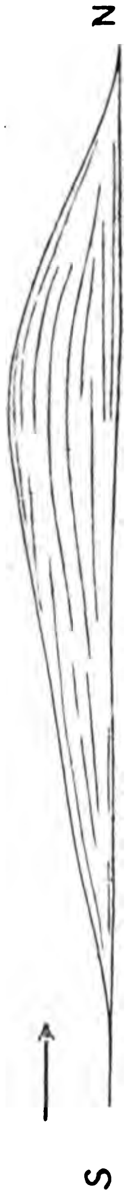


FIG. 82.—Medial Moraine, moulded into the form of a Drumlin.

boulders of the gneiss which Baltzer has described as forming the contact between the limestone and gneiss in the region south of Meiringen and Grindelwald.

The moraines between Gümlingen and Worb are in the form of ridges, many of which are made of a series of elongated hummocks, shaped like drumlins, and steepest at their northern ends. They are 'roches moutonnées' of till.

A series of ridges and terraces, and an old lake now filled with peat, 8 feet deep at least, occur about Konolfingen, the abundance of peat reminding one of Ireland.]

MENZINGEN

[I drive from Zug to Neuheim, viâ Baar, thence to Menzingen, returning to Zug viâ Allemvinden.

High up on the mountain, at Hinterberg, is a great moraine. Heaped up in huge conical hills, the moraine here on top of the mountain is more striking than I have seen it anywhere in the world. It is composed of coarsely stratified till.

The scratches have disappeared from the pebbles, which have otherwise the shape of those in true till. It is a *washed medial moraine*, not a kame.

Although so sandy and washed, I find striated erratics and many *perfectly angular* fragments in it.

This last is characteristic of moraines, and does not occur in *Nagelfluh*, or in terraces or kames. Great rounded masses of *genuine clayey till*, full of scratched pebbles, occur, imbedded in it like boulders.

Such a till boulder, 6 feet in diameter, was seen in the moraine at Menzingen.

It is nearly round, and very compact.

Was it frozen? This, then, is *younger than the compact till.* The latter was made during the advance, and the former at the time of greatest extension of the glacier.]

THUN TO WIMMIS

[I walk from Thun to Kanderbrücke. Here in an artificial cutting of the Kander is an excellent section of a medial moraine, showing unconformable superposition of till on old diluvium. Clearly glaciers of the first glacial epoch did not reach out as far as Thun (though they may have reached to Innspruck ?).

The gravel and sand underlying the till is true '*löcherige Nagelfluh*,' being in great part compacted to a hard conglomerate with layers of sandstone.

This material was hardened before the glacier came here. It was made at the edge of a lake, apparently, when a mountain stream flowed into it. Delta deposits, as Bachmann has shown (*Der Kander*, p. 54), have this identical structure. It seems as if the Kander here had emptied into a great lake, which stood much above its present level. There seems to have been a *depression of* 150 *feet* here in early quaternary times, and the depression may have been somewhat greater in the Jura region about Basel.

I have already argued that before the maximum of glaciation in England and Ireland there was a similar depression. This deposit is clearly older than that of the great extension of the glaciers.

I now distinguish three kinds of moraines:—

1. *Talus moraine.* Near the modern glacier; in narrow valleys; purely angular. *Unworn* either by ice or water.

2. *Moraine proper.* Terminal or lateral moraines at the edge of the ice at the time of its extension into open ground. Rounded and angular rocks are mixed; a large part of the stones are striated. *Ice-worn.*

3. *Stratified moraine.* Made in valleys far from modern glaciers; in low ground where water freely plays, or in an angle between two glaciers where water plays. *Made purely by water.*

All possible gradations occur from one of these to the other. The pure typical form of any one of the three is rare.

All three occur in the great Aar-Kander glacier:—

1. At the Blauen Seeli.
2. At Thungschneit, Lake Thun.
3. Near Berne.

Intermediate stages between (2) and (3) are the most common forms of moraines in the valley south of Thun, while (2) is seen on higher ground, as at Belpberg and Gartenberg.

The extreme form of (3) graduates into kames, which have an anticlinal structure, and are purely water-made. Yet all of these are made in, under, or at the edge of the glacier. I am persuaded that whenever boulder clay or gravel is cemented into a rock, it has been submerged. (Strong argument against the submarine origin of kames.) Deposits made by glacial streams are never compactly cemented unless they have been submerged, and then only when they contain much lime.]

Observations near Biberach

[The *Nagelfluh* is not due to an extra-morainic lake, being much older than the moraine, and showing no signs of iceberg-action.

The boulder clay is clearly a very distinct formation from the *Nagelfluh* on which it unconformably lies. It is full of lime, and has been much changed by the soaking out of the lime.

It seems, indeed, to have furnished the lime for the cementing of the *Nagelfluh*, a thing done, of course, under water.

Fraas and Rabst both consider that the cement of the *Nagelfluh* was obtained from this 'Blocklehm,' and the fact pointed out to me by Professor Baltzer, that where under such clay the *Nagelfluh* is often more strongly cemented *above* than *below*, is further evidence.

Is not the *löcherige Nagelfluh* simply and purely the result of the *elevation* of the Alps, made during that elevation and because of it? And is not the miocene *Nagelfluh*, which very closely resembles it, similarly made during, and by reason of, an earlier raising of the Alps?

These peculiar formations are absent in other countries because of no similar elevations. (Miocene *Nagelfluh* occurs in Italy.) And are not other great conglomerates, like the permian and Bünter in England, the triassic and millstone grit in America, the Oriskany, &c., also made during, and proof of periods of, elevation?

At such periods fresh surfaces are continually exposed to erosion, and a series of river deposits are made one above the other. Here at last I find the *origin* of the two great *Nagelfluhs* of Switzerland.

Bachmann was wrong about the great lakes, although right in considering *Nagelfluh* a *delta deposit.* A lake deposit, except at the entrance of mountain rivers, is a clay deposit.

This *Nagelfluh* is the deposit of a *succession of mountain rivers*, the succession being due to *continued elevation.*

This explanation has only come to me after two months of work and careful study of the subject. These old rivers drained into the Danube.

The elevation of the Alps in late pleiocene and early glacial times also elevated the Jura, and reversed the drainage of the Rhine, elevating the Sandgau and the old Rhine bed. This accords with the conclusions of LYELL (*Elements of Geology*), DESOR (*Bull. Soc. Géol. de France*, 2e sér. t. viii., p. 69, 1850), MÜLLER (*Verh. Naturf.-Gesells. Basel*, 2, p. 348), KOECHLIN (*Bull. Soc. Géol. de France*, 2e sér., t. xvii. p. 92), KOECHLIN, Sohn (*Géologie du Haut-Rhin*, pp. 100, 101).

I again cross the moraine, now from north to south. It is very wide, and without conspicuous hills, and would not be noticed by a geologist who was not experienced in glacial studies. In its great width and comparative flatness it is like portions of the Rhone glacier moraine, which on that account has been overlooked by geologists. Professor Chamberlin says of the American moraine that it is distinguished by the amount of drift rather than by any sharp ridge-like form; and this is clearly a characteristic of all great glaciers as distinguished from smaller glacial tongues.

Medial moraines are sharper and more hummocky, this being due, as I saw at Grindelwald, to the actual forcing up of the *ice* into great waves, a hundred or more feet high.

This is not the case with terminal moraines.

I take the train. We pass into the moraine beyond Waldsee, the moraine curving, and in the railway cuttings find an abundance of great boulders, often scattered, which project through the grass, as I saw so frequently in England.

At the station at Rossberg some large erratics have been piled up in the garden. One of these is of granitic gneiss, fully 15 feet high and 6 feet wide, the largest erratic preserved in South Germany; and another is almost as large.

About Wolfegg the moraine is enormously developed, and of great thickness, being here probably medial between two ice-lobes. Large hills are thrown up, and are cut through by the railway before we reach Wolfegg Station. The depth of the drift is seen in a gorge; it must be 400 feet thick.

This is an excellent example of the tumultuous character and great and sharp development of a medial moraine, as distinguished from a terminal one.

The moraine has evidently altered the drainage here, and made a watershed.

Formerly, probably, the Argen went by way of Leutkirch into the Iller, or *vice versâ*. There are no signs of glaciation here.]

That the extra-morainic drift is not older than the moraine, but due to the same cause, is indicated by the elevations; *both have the same elevation above the sea.* Both Fraas and Zittel think that Bach's hypothesis of two ice periods to explain the Biberach drift is without sufficient proof (vide *Sitz. d. math. phys. Classe*, 7 November, 1884, p. 272).

Probst also (*Württ.-naturw. Jahreshefte*, 1874, 40) is much opposed to two glacial epochs.

The *löckerige Nagelfluh* is striated by a glacier which passed over it near Schaftlarn, in Bavaria (Zittel, p. 279). Zittel never observed glaciated stones or erratics *in it.*

Schloss Zeil (ober Zeil)

[After visiting Schloss Zeil I examine a very instructive exposure behind a crucifix at the side of a wood, north of the castle.

Here a cutting shows *löcherige Nagelfluh* with the characters of a moraine. It is full of glaciated erratics, fragments of hornblendic gneiss—often quite angular—scratched limestone boulders, sandy layers, &c.; greatly resembling a mass of till. Yet it is firmly cemented into rock, and is somewhat rotted through the dissolution of the lime cement. It is cemented more on top than below.

This is the very top of the *löcherige Nagelfluh*, and here is an interesting transition from ordinary non-glaciated *löcherige Nagelfluh* into glaciated fringe material. It is an important locality.

It connects the pre-glacial with the glacial age without a break, and shows the passage of the rivers of the *Nagelfluh* period into the extra-morainic lake of the glacial period, there being here no unconformity.

Here also, at the side of Schloss Zeil, is a great pre-glacial valley, where the old Rhine passed on its way to the Danube, the Nagelfluh river continuing until it was dammed up by the great moraine below us, which is like an artificial dam across the valley, and now makes a watershed. The Biberach glaciated clay was unconformable, but here no unconformity can be proved.

Löcherige Nagelfluh, in its ordinary character of a river delta deposit, is seen in an exposure in a gravel quarry near a spring, not far from the carriage road to Leutkirch, north-east of the town.

The pebbles here are all rounded, and no striæ are seen on them.

Many of them are cracked by pressure.

Angular fragments are absent. An iceberg perhaps grounded at the former locality. There is not so much hornblendic gneiss here.

That icebergs grounded here is shown by two large erratics of gneiss in the town, a yard long.]

PFULLENDORF TO BASEL

[The Falls of the Rhine, then, are post-glacial, as are most falls.

The gravel in the Klettgau is in large part hardened into *löcherige Nagelfluh*; here it is undoubtedly a river deposit, made *before* the greatest extension of the glacier, for the moraine made at that time altered the drainage. The entrance of the old Rhine into the Klettgau seems to have been *below* the present Falls. Here is another means for calculating the age of the glacial epoch.

At Waldshut we descend to the valley of the present Rhine, which has greatly cut down its bed in post-glacial times, and, by contrasting the height of the old and the new bed, we gain a good idea of the amount of erosive work done since the glacial epoch by the Rhine.

(I have seen the Klettgau, Sandgau, Thurgau, Allgau, &c.)

Just before reaching Albert-Hanenstein Station is a large mass of yellowish clay full of boulders, often a foot long, this being the Philadelphia brick-clay due to the drainage of the glacier. It lies high upon the valley like the Philadelphia brick-clay, and might at first be taken for till, but it lies upon non-glaciated rocks, and crags project through it.

Below here the river flows more quietly, and has not cut through its plain of *Trenton gravel.*

As below Trenton, so at Murg and Säckingen, cliffs of river gravel occur, while back on the hills is the boulder clay, or brick-clay, and the older gravel phenomena are identical with those on the Delaware River. The gravel is partly cemented, showing that there may be *three Nagelfluhs*: a miocene, a pleiocene, and a post-glacial.

This partly cemented gravel is probably of the same age as the one I saw at Pfullendorf. It here makes the floor of the valley.]

The pre-glacial Rhine

[From studies both in the Sandgau, in the Frickthal, and along the edge of the Rhine and Rhone glaciers, I am now convinced that:—

1. No glaciers came as far north as Basel from Switzerland.
2. That the pre-glacial Rhine flowed from Frankfort southward to Mülhausen, and south-west through the Sandgau to the Dules Valley.
3. That the change in direction of the flow of the Rhine was due to a quaternary elevation of the Jura.

As to elevation in glacial times we have excellent evidence (1) in the *löcherige Nagelfluh* all along the north side of the Alps; (2) in the folding, faulting, and tilting of miocene strata in post-miocene times (STUSER, *Geologie d. Schweitz*, ii. 470, &c.).

I now fully concur with the views of Koechlin, Lyell, Desor, &c.—all of whom held that the last movements of the Jura have elevated the gravels of Bettlach and the Sandgau to their present high position.

Another instance of a river having altered its outlet occurred in China in 1852-53 (*Geological Magazine*, April 1878), when the Yellow River, or Whang-Ho, formerly emptying into the Yellow Sea, in 33° N. latitude, altered its course so as to pass into the Gulf of Pee-chee-lee, in 37½° N., the two outlets being separated by the mountains of Shaw Tung, or East Mountain, and by a distance measured along the coast-line of 640 miles.]

The drift of Belgium

No traces of glaciation have been observed in Belgium. Large blocks have been carried northward down the Meuse from the Ardennes by floating ice-cakes, a proof of colder conditions than now exist.

Gravels containing sometimes fresh-water shells occur over much of Belgium up to 150 metres, and these gravels are overlaid by a loamy or loess-like deposit called *Limon Hesbeyau*.

This is homogeneous, and rises up to about 150 metres; its origin has been much discussed, and is not understood.

It may be due to a great fresh-water lake, caused by ice damming up the mouth of the Rhine. The Rhine now flows along the *edge* of the former ice-sheet, like the Missouri, the Alleghany, the Weichsel, &c. Papers on the quaternary of Belgium have been written by Van der Brocke, Rittot, Cogles, Van Ertborne, Del Veaux, &c.

(A large part of the foregoing information was courteously given me by Dr. Raymond Storms.)

HOLLAND

[Going west from Arnheim, we enter a region deeply covered by sand and gravel, rising higher than the flat country farther south. I see no true till. The deposit is not a moraine, as I formerly thought, but is aqueous, being made of yellow gravel and sand, not unlike the Glassborough (New Jersey) yellow gravel of late tertiary age.

Sand dumps are seen, but no till; no moraine meres or evidences of glaciation; and the true moraine of the ice-sheet invading Germany is farther north.]

PRINTED BY
SPOTTISWOODE AND CO., NEW STREET SQUARE
LONDON